RAND

Finding the Right Mix of Military and Civil Airlift, Issues and Implications

Volume 2. Analysis

Jean R. Gebman, Lois J. Batchelder, Katherine M. Poehlmann

Project AIR FORCE

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FOREWORD

Shortly after our forces returned from the Gulf War, the Secretary of the Air Force and the Air Force Chief of Staff asked RAND to undertake this research. The work was performed and briefed to the Air Force during fiscal year 1992. The following year, a summary briefing was prepared and presented to the Air Force. Draft documentation was then prepared and reviewed within RAND. During 1994, a revised draft report was reviewed by the Air Force and the aircraft industry.

RAND was asked to perform this work in response to the many changes occurring around the world that may influence the attractiveness of different approaches to the Air Force's investment in its strategic airlift capabilities. Changes have continued to occur through the course of the research and its documentation. They may continue as the Air Force and the Department of Defense continue to grapple with major choices about essential airlift capabilities and the alternatives for providing those capabilities.

The research described in this report can help inform those choices. It explores how the DoD might work toward an affordable strategic airlift capability that has both enough capacity to support major regional contingencies and enough flexibility to go anywhere our nation's interests require the prompt global reach of our combat or humanitarian resources.

Because the DoD's choices in this area involve major investments that will have significant and long-lasting implications for future capabilities, we have aimed to provide the Air Force with an independent research product based upon a broad analysis of matters we judged to be germane to future choices.

As the research and its documentation progressed, there have been many spirited discussions within RAND and the airlift community. These discussions have contributed importantly to the nature and content of the final report. To share the benefit of many of these discussions with the reader, we have included a third volume. It contains 80 topics that are arranged by subject matter in a set of appendixes.

Some of the topics address the research context (Appendix A), others deal with elements of the research (Appendixes B, C, and D) or differences between this and related research efforts (Appendix E). One set of topics (Appendix F) illustrates how this research might be adapted to take into account the continuing changes that are important to future decisions. The final set of topics (Appendix G) identifies impor-

tant open issues and suggests initiatives for resolving or narrowing these issues. Some key areas to watch are the DoD's continuing assessment of airlift requirements, the DoD's continuing revisions to the CRAF program, the CINCs' perspectives on the need for capacity and flexibility in the airlift fleet, the DoD's Nondevelopmental Airlift Aircraft program, and the retirement of the C-141 fleet.

PREFACE

Stringent budgets and a changing world prompted the Secretary of the Air Force and the Air Force Chief of Staff to seek an independent estimate of the mix of military and civil airlift that would be sufficient for future needs while minimizing demands on future budgets.

Most of the research for the short-term effort described here was completed during the first six months of fiscal year (FY) 1992, with the remainder of the year devoted to analysis of the Air Force's follow-up questions. The research built upon other RAND work begun in 1990 for the Office of the Undersecretary of Defense for Acquisition (Hura, Matsumura, and Robinson, 1993); reviews of lessons learned from the Gulf War that were conducted for the Office of the Secretary of Defense, the Army, and the Air Force (Lund, Berg, and Replogle, 1993, and Chenoweth, 1993); and research requested by the Vice Chief of Staff of the Air Force that addressed the subject of the base force (Bowie et al., 1993). In adding to the airlift analysis methods used in the previously initiated work, this research developed advances in RAND's tools for analyzing life-cycle cost, benefits of aerial refueling, aircraft utilization rates, throughput, and airfield access.

As research results were produced, they were briefed to the Air Force throughout 1992. At the Air Force's request, a summary briefing was prepared and provided in February 1993. This report presents the details of the research and findings reported in that summary briefing. This report and its companion volumes (Gebman, Batchelder, and Poehlmann, 1994a,b) are the final documentation for this research. Since completion of the research in 1992, a number of events related to this research have occurred:

- To expand its authority to activate the Civil Reserve Air Fleet (CRAF) without requiring action by the President (which is needed for Stage III), the Department of Defense (DoD) has increased the size of Stages I and II. For example, Stage I for passenger aircraft is 63 percent larger. Stage II for cargo aircraft is 100 percent larger.
- DoD's continuing revisions to the CRAF program are more broadly linking government business to participation in the CRAF.

- Estimated costs for completing the C-17 program have risen, the schedule has been stretched, and the airplane's payload has been reduced for long distances.[1]
- A congressionally mandated Cost and Operational Effectiveness Assessment for the C-17 was completed by the Institute for Defense Analyses in 1993.
- DoD's continuing assessment of airlift requirements is showing increased needs for airlift during the early weeks of a major regional contingency and even greater needs during the early weeks of a second, nearly simultaneous major regional contingency.
- The perspectives of the commanders in chief (CINCs) of the unified commands on the need for capacity and flexibility in the airlift fleet are reflected in the outcome of their August 1993 meeting, in which they expressed a very strong desire for a new military-style transport with flexibility like that possessed by the C-17.
- The DoD has launched a Nondevelopmental Airlift Aircraft program to explore alternatives, including military- and civil-style transports that might be procured along with or instead of the C-17.
- The DoD has initiated a study of strategic airlift force miles.
- The entire C-141 fleet is now scheduled for retirement by 2005.

Although the appendixes (Volume 3) address how some of the changes since the completion of the research in 1992 may affect the appropriate use of our work, we have not tried to update the results of the research to account for the continuing stream of changes.

This report is being published at this time to illuminate issues and to illustrate their implications so as to help inform the choices the DoD faces as it searches for the right mix of military and civil airlift.

This project was conducted within the Resource Management and Systems Acquisition Program of RAND's Project AIR FORCE, the Air Force's federally funded research and development center for studies and analysis.

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[1]The Institute for Defense Analyses has performed a Cost and Operational Effectiveness Assessment. The General Accounting Office has reviewed the status of the C-17 development program. The Defense Acquisition Board has considered restructuring the acquisition program. The DoD and the C-17's prime contractor have agreed to a restructuring of the acquisition program, including reduced performance requirements for the aircraft. The DoD is considering supplementing its procurement of the C-17 with the purchase of an already developed transport.

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The objective of this research was to produce a best estimate for the optimum mix of civil and military airlift that could serve future demands at the least cost. The Air Force sought an independent estimate of this *right mix* because the cost of maintaining the nation's emergency airlift capabilities is very sensitive to choices about the mix of civil and military airlift and to choices about the quantities and types of transports owned and operated by the government. On the one hand, military-style transports, especially the C-17, offer the most flexibility; on the other hand, civil-style transports offer the least costly approach for delivering passengers and small items of cargo to airports with well-established facilities. The civil-style transport becomes especially attractive when it can be called upon from the civil sector only to augment military airlift during a very large crisis. The Civil Reserve Air Fleet (CRAF) has provided such a standby capability since the early 1950s.

The Air Force had both general and specific requirements for RAND's estimate of the right mix. Generally, it wanted the estimate to address the following question: *What is the most efficient mix of civil and military airlift resources that will provide sufficiently robust capabilities across the range of scenarios and situations for which the Air Force must be prepared?* Specifically, the Air Force wanted to know whether it could cut costs with policy choices, such as

- Stopping the C-130 production line now and relying later upon the C-17 to provide necessary replacements for retiring C-130 transports
- Buying fewer C-17s and relying more on civil airlift.

THE DEMAND FOR AIRLIFT IS CHANGING

The enormous airlift needs imposed by the Cold War strategy that called for quick reinforcement of NATO's established theater led to a heavy emphasis on transports, such as the C-5, that could quickly move combat equipment. Some of that equipment, called outsize, could only be moved by the C-5. The Army, which has most of the military's outsize materiel, requires a very high number of C-5 missions to airlift its mechanized and armored divisions. Because the United States could not afford enough military airlift to meet the needs of executing the strategy with airlift alone, a large CRAF was established. Other means, such as prepositioning and sealift, also became important parts of the mobility strategy.

The Gulf War presented a more distant region than that of the Cold War's scenarios, increasing deployment distances by over 50 percent and requiring the Army's mechanized and armored divisions to be delivered by sealift. It also presented a relatively barren theater with different needs. If future demands are similar, a broader mix of loads will need airlift services. Initially one-half of the cargo shipped by air during the Gulf War was bulk cargo. That proportion later expanded to three-fourths. Bulk cargo can be carried in the baggage compartment of civil transports, as well as on the main deck of civil transports that have been configured as freighters, and of course bulk can be carried on the military transports (C-141 and C-5).

The emergence of demand for bulk cargo raises a serious question about the DoD's 1992 plans for altering the composition of the airlift fleet. Those plans would have increased the amount of outsize capacity from about one-third to two-thirds of the total airlift capability for cargo, assuming CRAF provides the same level of service used during the peak month of the Gulf War airlift. Given the high cost of outsize capabilities and the modest demand for outsize airlift during the Gulf War, the DoD is faced with a major decision regarding the composition of the military airlift fleet. At the time of this report's publication, the DoD was reconsidering its 1992 plans, and Congress had authorized exploration of alternative transports, including civil-style transports.

THE SUPPLY OF CIVIL AIRLIFT HAS SERIOUS LIMITATIONS

The large air carriers are finding it difficult to continue their past support of CRAF in light of the disruption to their routine operations that activation of CRAF caused during the Gulf War and the possibility of even greater disruption during future crises. Furthermore, too heavy a reliance on the civil airlift sector may lead to too high an expectation on the part of the air carriers regarding activation of their resources to support crises. For reluctant participants in the CRAF program, a perception of high likelihood of activation could cause carriers to reduce their participation. This would be unfortunate, because the CRAF program has provided significant, inexpensive augmentation of military airlift capabilities. Thus, for fleet-planning purposes, the Gulf War–level of support from the civil sector seems to be the most prudent expectation of CRAF's availability for most crises in which CRAF would be activated.

To maximize dependable participation in CRAF, the Air Force needs to set realistic expectations for its size and make sure that the military airlift fleet is large enough and versatile enough that CRAF would rarely have to be activated.

THE SUPPLY OF MILITARY AIRLIFT NEEDS TO CHANGE

This research addressed the need perceived in 1992 to replace two-thirds of the C-141 fleet and for the remaining third to have extensive modifications to extend its service life. Our analysis of alternative airlift fleets illustrates an almost four-to-one cost-effectiveness ratio advantage for a civil-style transport, such as the 747-400F,

over the C-17 for movement of bulk cargo.[1] The advantage for movement of troops is comparable. The currently configured C-17 will carry about 100 troops, whereas a 747-400F equipped with seating pallets could carry about 400. A 747-400F costs slightly less to procure than a C-17

Although the C-17 has greater ground agility than a 747-400F, we found that the ramp space required per ton of cargo delivered was comparable.

In terms of the types of aircraft arriving in theater, a fleet with 42 747-400F aircraft instead of a fleet with 120 C-17s would increase the number of civil-style transports arriving daily in theater by adding 13 daily arrivals by a DoD-operated 747-400F to the base case of 16 daily arrivals by CRAF. This, of course, would change the requirement for ground handling equipment. For unloading equipment, the civil-style transports are at a disadvantage relative to the military-style transports, because the latter have low cargo decks and ramps that facilitate rolling on and rolling off of vehicles. For unloading bulk cargo, however, civil-style transports, such as the 747-400F, have automated loading systems built into the aircraft that facilitate the loading and unloading of containers and pallets. Military-style transports have low cargo decks and pallet systems, although not automated, that allow forklifts or other materiel-handling equipment to accomplish unloading.

AIRFIELD ACCESS IS A MAJOR FLEET-COMPOSITION ISSUE

Regarding airfield access, many dimensions must be evaluated when assessing the political and physical suitability of a particular airfield. In this research, we focused on physical suitability, which revealed the greatest differences between aircraft. The military transports can routinely use about three times as many airfields as a large civil-style transport like the 747-400F. Although the C-17 has clear advantage over other transports in its ability to operate from short, narrow runways, the C-5 and the C-130 have an advantage over the C-17 in that they do not require runways as strong as those the C-17 requires. From a comparative standpoint, although the C-17 is designed to perform the same types of missions, it is clear that the C-130 enjoys greater access to airfields than the C-17. Whether or not the C-17 has greater airfield access than the C-5 depends upon technical issues regarding the prudence and consequences of overstressing runways. The C-17 may enjoy up to a 100-percent increase in airfield access over the C-5, depending upon one's view of these issues. We observe, however, that the C-17 has weight-bearing characteristics very similar to those of the C-141, which has less access to airfields around the world than the C-5, according to the Air Mobility Command's airfield suitability database.

[1]Subsequent research by others indicates that the advantage may be only 1.3 to 1 (see Appendix E in Volume 3).

ACAS	Airlift (mission) Cycle Analysis System
ACN	Aircraft classification number
AFP	Air Force Pamphlet
AMC	Air Mobility Command
APOD	Aerial port of debarkation
APOE	Aerial port of embarkation
C^4	Command, control, communication, and computers
CBR	California Bearing Ratio
CONUS	Continental United States
CRAF	Civil Reserve Air Fleet
DMA	Defense Mapping Agency
DoD	Department of Defense
GSA	General Services Administration
kts	Knots
LCN	Load classification number
MAC	Military Airlift Command (now AMC)
MATS	Military Air Transport Service
MOG	Maximum on ground
n mi	Nautical mile
O&S	Operations & support
PAA	Primary assigned aircraft
RDT&E	Research, development, test and evaluation
RM&A	Reliability, maintainability, and availability
SARs	Selected Acquisition Reports
SPO	System Program Office
TAI	Total aircraft inventory

Chapter One

INTRODUCTION

OVERVIEW

As our national security strategy is adapting to a changing world, intertheater airlift remains an important instrument for implementing foreign and defense policies, because it provides the Department of Defense (DoD) with the ability to deliver combat forces or humanitarian relief rapidly anywhere in the world and to follow through quickly in response to changing circumstances. Military airlift, however, is the most costly mode of transportation, because it requires specialized military transports that are more expensive than civil transports and are not as fully utilized between crises. Even during the height of the Cold War, the DoD's total supply of military and civil airlift was constrained by budgets and fell short of being sufficient to support the national military strategy for reinforcing NATO. Because our national security strategy continues to place high demands on airlift, and because the supply of airlift will remain fiscally constrained,[1] it is important to invest wisely in the right mix of capabilities.

Recognizing that both the division of airlift services between civil and military airlift and the composition of the military airlift force structure may need to change in response to changing world conditions, lessons from the Gulf War, the continuing reduction in force structure, and the prospect of even tighter budgets, the Air Force's leadership asked RAND to undertake this research at the close of fiscal year (FY) 1991.

To provide the reader quick access to specific topics, there is a flowchart at the front of each chapter that outlines the chapter's contents and illustrates the flow of information between the principal sections of the chapter. See Figure 1.1, which is the first of these.

[1]Although fiscal constraints on strategic airlift can be adjusted (up and down) as resources are allocated to different mission areas, history strongly suggests that the strategic airlift mission area will always be constrained by resources, even during the best of times. Moreover, with prepositioning and investments in faster sealift ships competing for shares of DoD's investment in mobilization, any serious relaxation of fiscal constraints on strategic airlift seems unlikely.

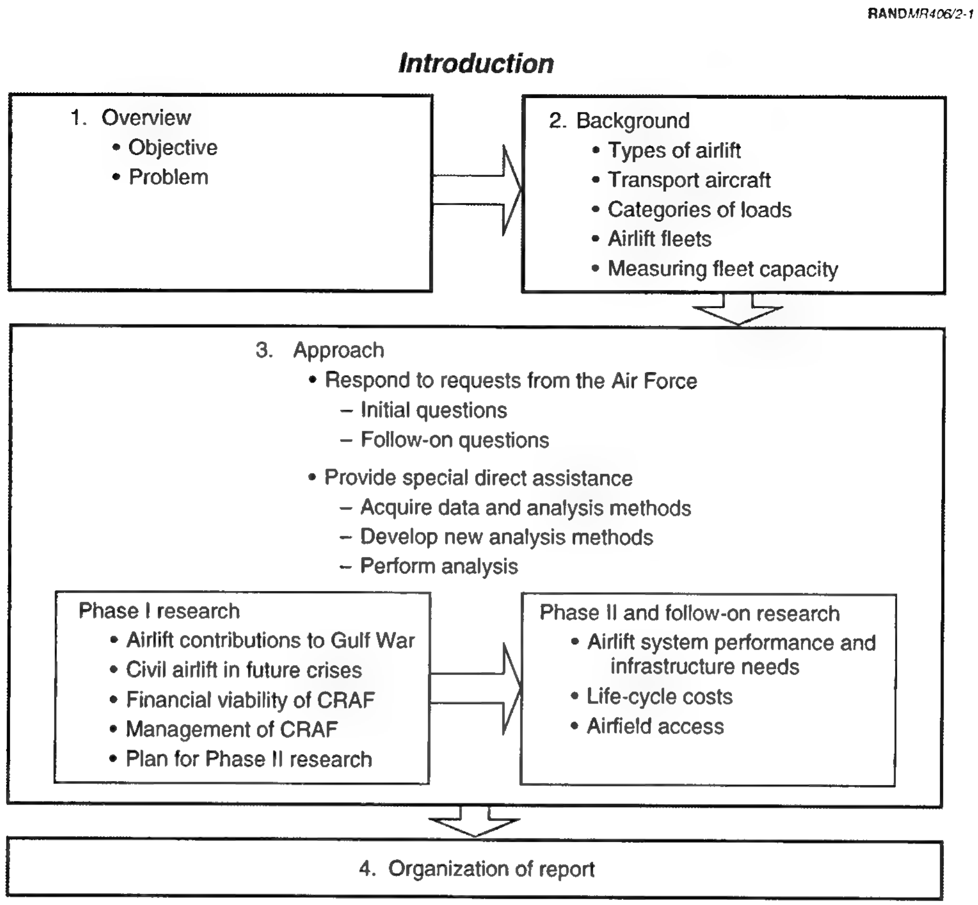

Figure 1.1—Flowchart for Chapter One

Objective

The objective of this research was to contribute to the Air Force's investment planning process for airlift by producing a best estimate for the optimum mix of civil and military airlift that could serve future demands for intertheater airlift at the least cost. This means delivering what is needed to the places where it is needed and at the time it is needed. To satisfy all of these needs, the airlift fleet must have the right mix of capacity to maintain the necessary flow and of flexibility to adapt to the capabilities and limitations of the airfields in the region. The Air Force sought an independent estimate of this "right mix" because the cost of maintaining the nation's emergency airlift capabilities is very sensitive to choices about the mix of civil and military airlift and choices about the quantities and types of transports owned and operated by the government. On the one hand, military-style transports, especially the C-17, offer the most flexibility in terms of delivering large items of military equipment either by airdrop or by landing at airfields with limited facilities and runways. On the other hand, civil-style transports offer the least costly approach for delivering passengers

and small items of cargo to airports with well-established facilities, such as runways that are both long and strong. The civil-style transport becomes especially attractive from a cost standpoint when it can be called upon from the civil sector only to augment military airlift during a very large crisis. The Civil Reserve Air Fleet (CRAF) has provided such a standby capability since the early 1950s.

The Air Force had both general and specific requirements for RAND's estimate of the right mix. Generally, it wanted the estimate to address the following question: *What is the most efficient mix of civil and military airlift resources that will provide sufficiently robust capabilities across the range of scenarios and situations for which the Air Force must be prepared?* Specifically, it wanted to know whether it could cut costs with policy choices, such as

- Stopping the C-130 production line now and relying later upon the C-17 to provide necessary replacements for retiring C-130 transports
- Buying fewer C-17s and relying more on civil airlift.

Problem

The problem of finding the right mix of military and civil airlift has four parts that must be addressed: (1) changing demand for airlift, (2) changing supply of airlift capability, (3) fiscal considerations, and (4) the investment-planning process.

Changing Demand for Airlift. The changing demand for airlift needs to be more fully factored into the airlift investment planning process. The world has changed since the concepts for the current military and civil airlift fleets were developed during the 1950s and 1960s and since the concept for the C-17 was defined during the early 1980s. Initially, the C-17 was envisioned as a medium-large transport, about two-thirds the weight of a C-5, that would be procured in large quantity (210 aircraft) to reinforce NATO's frontline units directly or to deploy combat units rapidly to forward operating locations in other theaters, such as the Middle East. It would blend the large-size cargo capability of the C-5 with the small-austere-airfield capabilities of the C-130 to deliver combat equipment directly to frontline units. Such reinforcement was viewed as vital to fending off assaults by the larger numbers of tanks held by the Warsaw Pact and the Soviet Union. In other theaters, the ability to deliver combat units rapidly to forward locations was seen as a way to counter the assaults of other prospective adversaries. By 1991, however, it was no longer obvious that such plans would best serve future needs. The Gulf War airlift, for example, moved mostly smaller items that can be carried on civil transports. Although future needs are uncertain, a military airlift fleet sized to carry tanks no longer appears necessary.

Changing Supply of Airlift Capability. The amount of current airlift capability and changes in the supply of that capability need to be more realistically addressed in the airlift investment-planning process. Further changes to the supply side are needed to more efficiently use military and civil airlift and to deal with the aging fleet of military transports.

Both our modeling of the airlift system and our analysis of the Gulf War airlift show that the DoD only has about half the usable supply that is suggested by traditional planning factors. Furthermore, the Air Force now faces significant retirements of aircraft over the next 15 years, because 87 percent of its 386 intertheater transports have been in service for 20 to 30 years (Figure 1.2). Two-thirds of its fleet of 260 C-141 transports are already scheduled for retirement during the 1990s.

Although improving the efficiency with which airlift resources are employed will help raise the level of usable capabilities, the civil aviation's historical levels of commitment can no longer be taken for granted for at least four reasons:

1. Normal airlift business that the military provides to air carriers is small and declining.
2. Air carriers are more fully considering how compulsory activation of their resources can introduce hard-to-recover costs, including damage to market share.
3. The financial problems facing the civil aviation industry are forcing carriers to avoid risks that fail to provide sufficient opportunities for profit.
4. Air carriers will have less to offer because smaller proportions of their fleets will be in the form of the very large aircraft that proved best suited to the military's needs during the Gulf War airlift.

Fiscal Considerations. Fiscal constraints, which have limited the overall amount of airlift capacity since the 1940s, have become even tighter and are forcing a reconsideration of the airlift investment strategy, because airlift costs are very sensitive to the mix of military and civil resources and the composition of the military airlift fleet.

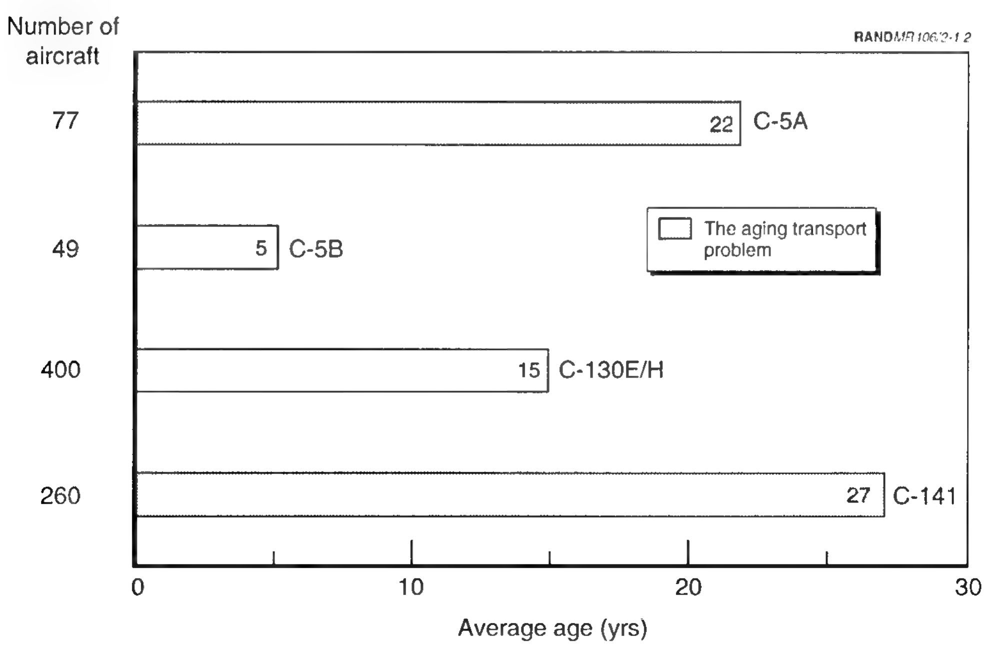

Figure 1.2—DoD's Aging Transport Problem

The Air Force's historical levels of support for the acquisition and operation of its military transports also can no longer be taken for granted as every element of the defense budget comes under even closer scrutiny. Of special concern is the relatively large investment in the C-17,[2] which was planned to replace retiring C-141 and C-130 transports. It has become the Air Force's largest remaining procurement for the 1990s.

Furthermore, major investments are pending for other elements of intertheater mobility. New expenditures on faster and greater-capacity sealift and increased prepositioning of materials abroad mean that the strains on the mobility portion of the Pentagon's budget may be particularly acute.

Investment-Planning Process. Meanwhile, the Air Force's investment-planning process has remained focused on traditional military values, such as flexibility, and it has been hampered by deficiencies and limitations of analytic tools for assessing airlift capability and total life-cycle costs. The traditional focus on military flexibility needs to be expanded to include consideration of means for more efficient movement of the kinds of materiel that can be carried by civil transports. Such expansion of the focus requires a new approach and new tools for explicitly analyzing capabilities and costs of alternative fleets in ways that realistically account for utilization of resources and total costs.

BACKGROUND

Finding the right mix of military and civil airlift capabilities requires a certain familiarity with the types of airlift, transport aircraft, categories of loads, the airlift fleets, and the DoD's approach to measuring fleet capacity for airlift. Readers familiar with these matters may want to go to the next subsection, which describes our approach to the research.

Types of Airlift

The military airlift force structure, since the 1950s, has been divided into intertheater and intratheater airlift. While large, long-range transports have provided intertheater airlift, smaller, shorter-range transports have provided intratheater airlift services. The C-17 has been envisioned as an airplane that would be suitable for both intertheater and intratheater missions. As such, it would possess the unique capability of flying intercontinental ranges and landing at small, austere, in-theater airfields that otherwise could be serviced only by intratheater transports like the C-130.

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[2]At the beginning of FY 1992, the acquisition plan called for a total investment of $35 billion (then-year) for research, development, and production of 120 aircraft. Through FY 1992, the DoD had been authorized to use $11 billion of this amount.

Transport Aircraft

Military-Style Transports. The Air Force's current fleet of transport aircraft (Figure 1.3) has a distinctive style that features significant military advantages over civilian airlift. All of these military-style transports are designed to use airfields with no preexisting infrastructure and with runways shorter than those normally used by long-range civil transports. They also are designed so that vehicles and equipment can easily roll on and off without the requirement for substantial materiel-handling equipment and personnel at the on-load and off-load points. Moreover, the larger transports (C-141, C-5, and C-17) can carry materiel that will not fit on civil-style transports. Finally, each of the military-style transports can airdrop both personnel and materiel.

Furthermore, to help cope with the dangers of flight through threatening environments, military-style transports are designed with redundant systems and other special systems to minimize the effects of battle damage. Their designs include additional safety features, such as onboard systems to help suppress wing fires, and they, as do other Air Force aircraft, use a special fuel (JP-4) that was developed to minimize the dangers of battle damage to fuel tanks. Military-style transports are also designed to avoid threats. They are designed for flight in low-altitude flight regimes. They also are used to perform quick unloading on a runway. For example, such combat offloads allow a string of pallets to be extracted rapidly from an aircraft by a parachute as the aircraft rolls down a runway or, in the case of the C-130 and the C-17, flies a few feet above the runway.

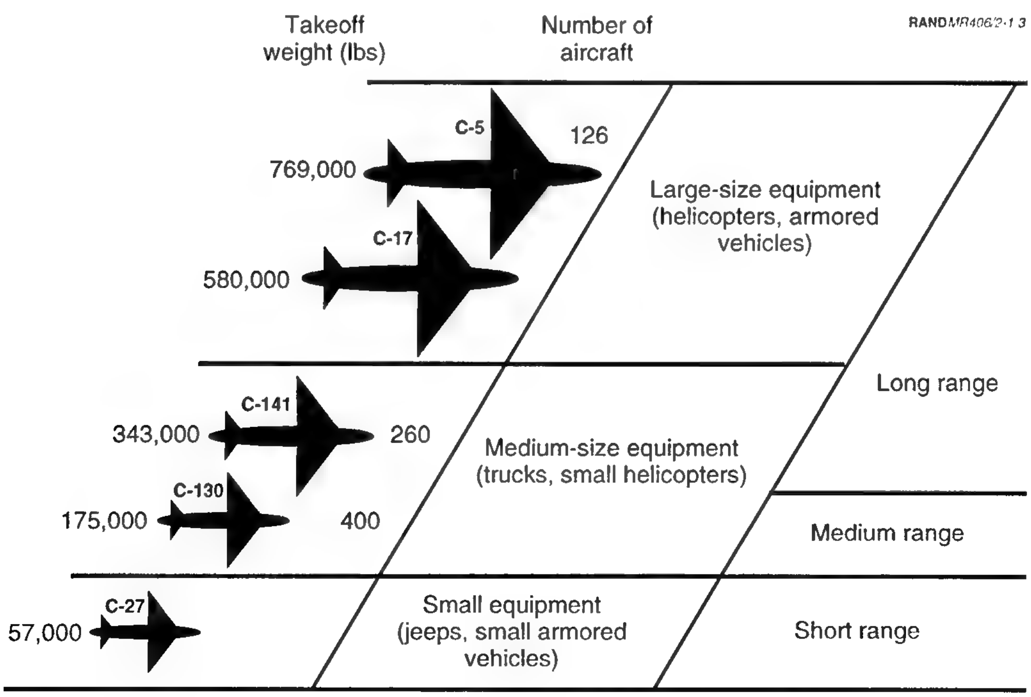

Figure 1.3—Military Transports Operated by the Air Force During 1992 and Under Development

In summary then, the military flexibility that is unique to the military-style transport includes (1) the ability to use airfields with no preexisting infrastructure, (2) the ability to carry large items of equipment, (3) ease of loading vehicles, (4) the ability to airdrop personnel and materiel, (5) the ability to minimize exposure to threats through low-level flight and through rapid offloads on runways, and (6) system designs that are damage tolerant.

To provide such military flexibility, these transports have several distinguishing features. Their airframes have high wings that allow the cargo decks to be close to the ground. They have large doors and built-in loading ramps that can be opened in flight for air drops. They have high ceilings in their cargo compartments. They have cargo decks strong enough to withstand the axle loads and tread loads of heavy equipment, some of which weigh more than 100,000 pounds. They also have a cabin structure with tie-down fittings to secure heavy loads to the aircraft while in flight, and they have special provisions for loading and securing cargo pallets. Finally, engines on the military-style transports are large to provide high thrust for using short runways. Although these distinguishing features of the airframes and the engines provide military flexibility, they also contribute to aircraft weight and limit aerodynamic efficiency. Consequently, these features necessarily contribute to the costs of building and using a military-style transport.

The C-130 and the C-141 were the first of this family of military-style transports to be built. The C-141 was developed and produced during the 1960s and is nearing the end of its economically useful service life unless there is a major overhaul and rebuilding of worn structures and systems. The C-5, developed during the late 1960s, was first produced during the early 1970s and then again when the production line was reopened during the mid-1980s to produce 50 additional aircraft.

The C-130 is smaller than the C-141, has a shorter range capability, and is slower because it has turboprop engines. Although not well suited for rapidly carrying large loads over great distances, the C-130 has proved very useful for moving troops, supplies, and small vehicles within a theater of operations. Moreover, it has an advantage in that it can operate into small airfields located in areas where terrain and short runways preclude the use of the C-5 and the C-141. It also can land on roads and dirt strips.

The C-130 advantage derives from differences between its turboprop propulsion system and the turbofans that power the C-5 and the C-141. The turboprops do not ingest loose material like the turbofans, and when placed in reverse pitch, they provide substantial braking power. They also provide more rapid changes in thrust, as compared to turbofans, a feature that contributes to short takeoff distances and quick-reaction maneuvers when descending to hard-to-access airfields. The turbofans on the C-5, C-141, and C-17, however, allow these aircraft to fly efficiently at speeds 50 percent faster than the C-130. The C-17 uses an unusually large thrust-reverser system and a unique arrangement of engines and flaps to provide C-130–like advantages for operating into small austere airfields that may be located in hard-to-access areas.

Finally, the C-27 is a small, short-range transport that can use airfields with landing strips too small for the C-130. The U.S. Southern Command is procuring a small

quantity of C-27s to improve its ability to access airfields in Central and South America.

Civil-Style Transports. While the evolution of the military-style transport has been driven by pressure to increase military flexibility, the evolution of the civil-style transport has been driven by competitive pressures to use advancing technology to reduce the costs of carrying large loads of passengers and/or cargo. To minimize the weight of the aircraft's structure and propulsion system, civil transports have doors no larger than necessary for the loading of passengers and baggage, floors constructed of plywood or other lightweight material, and simple lightweight thrust reversers. Even stairways are provided only at the air terminals rather than being designed into the aircraft. Every pound of weight that is squeezed out of the design of a civil transport's structure is one more pound toward the ability to carry another revenue-paying passenger or to fly to another revenue-generating destination.

Civil transports also have slender and highly tapered fuselages to minimize drag, thereby providing the greatest possible flight distances for a given load of fuel, passengers, and baggage. To minimize the size and weight of the fuselage, large civil transports have main passenger cabins with relatively low ceilings, overhead storage containers, and a high main deck, under which is stored passengers' baggage and other revenue-generating cargo. The intermodal container system added to the 747 freighters during the 1970s includes a built-in powered roller system for quickly moving containers up to 40 feet long on and off the aircraft. In addition to the efficiency of loading and unloading, civil air carriers have seen that special 10-foot–high containers are more efficient than pallets with 8-foot height limits.

Civil transports, their air terminals, and their ground operations are also geared to prepare the aircraft rapidly for its next flight. On domestic routes, aircraft ground times of less than 2 hours are often achieved, even on coast-to-coast flights. Even for long-range international flights, ground times of less than 3 hours are achieved, depending upon schedule needs and allowances for air traffic delays for arriving flights. Important contributors to short ground times for civil transports are capability to rapidly refuel aircraft, high reliability of civil transports, adequate quantities of ground servicing personnel and equipment, and general arrangement of the air-terminal infrastructure for rapid movement of passengers, baggage, and cargo to and from the aircraft.

Categories of Loads

Outsize. The class of largest equipment, termed *outsize*, includes any single item of air cargo that exceeds 1,000 in. long by 117 in. wide by 105 in. high in any one dimension and requires the use of C-5 aircraft. The C-17 is designed to carry most outsize equipment. Equipment in this class includes the M-1 Abrams tank; armored vehicles, such as the Bradley; artillery; vans and launchers for surface-to-air missile systems, such as the Patriot; and troop-carrying helicopters, such as the 33-passenger Chinook.

Oversize. This category includes air cargo that exceeds the usable dimension of a 463L pallet loaded to the design height of 96 inches but that is equal to or less than 1,000 in. long, 117 in. wide, and 105 in. high. The cargo must fit the dimension requirements of the C-130 and C-141 cargo doors and cargo compartments. Oversize includes such cargo as helicopters, tracked vehicles, and rolling stock. Depending upon floor strength, the size of the cargo door, and the size of the cargo compartment, freighter versions of wide-body civil transports can carry oversize equipment. A 747 freighter with a nose door or a large side cargo door can accommodate most oversize cargo. Other wide-body freighters, such as the DC-10, MD11, and 767, have less capability because of door and cargo compartment constraints.

Bulk. This category includes cargo that is within the usable dimensions of a 463L pallet (88 in. wide and 108 in. long) (see U.S. Air Force, 1987, p. 25). Bulk cargo can be carried on military transports, freighter-configured civil transports, and in the lower lobe of wide-body transports.[3] Civil-style transports, can also carry bulk cargo in containers that are placed on the main deck of a freighter-configured aircraft or containers that are put under the floor of the main cabin.

Airlift Fleets

Military Airlift Fleet. Regardless of the style of its transports, the distinguishing feature of the military airlift fleet has been the capability to conduct operations in hostile areas where crews and equipment may be put at substantial risk, risk that civilian pilots have the prerogative to avoid. The aircraft comprising the current intertheater airlift fleet are 260 C-141 transports and 126 C-5 transports. There also are 59 KC-10 aircraft that may serve as tankers or transports.

Because the composition of this fleet was driven by the Cold War's enormous requirement for the movement of combat units to reinforce our allies in Europe, the fleet was optimized to reinforcing NATO. Thus, the movement of combat equipment has dominated the design of the transports and the makeup of the fleet. Because the needs to move such equipment were so great, and never fully satisfied, the efficient movement of bulk cargo did not receive serious attention. For example, the system for loading and securing bulk cargo on military transports has seen few changes since the introduction of the 463L pallet system during the late 1950s. In theory, the military transports could also carry intermodal containers, such as those routinely carried by 747 freighters. However, such efficient movement of bulk cargo in containers by military transports has not been a matter of emphasis in the evolution of the military airlift fleet.

Civil Reserve Airlift Fleet. For 40 years, the Air Force has maintained an arrangement with the civil carriers to use the complementary strengths of military and civil airlift by drawing upon the civil air fleet to augment military airlift for major emergencies. The division of routine airlift services, since the late 1950s, has called for the

[3]The average lower-lobe capability of the DC-10 to carry bulk-palletized cargo is 15,000 lbs if the aircraft has restraint capability for the 463L pallet; the average lower-lobe capacity for the 747 is 27,000 lbs.

Air Force to haul most of the DoD's international cargo, while civil aviation hauls most of the DoD's passengers. In exchange for a share of the military's international air-transport business, each participating air carrier offers a portion of its fleet to be called upon in the event of a major national need for augmentation of military resources. CRAF started with a few tens of aircraft in the early 50s and grew to about 400 long-range international aircraft by the end of the 1980s. At very little cost over a four-decade period, the Air Force maintained a very substantial reserve capability in CRAF, even though it was never activated until the Gulf War.

The current form of CRAF includes six segments: (1) domestic, (2) Alaskan, (3) short-range international passenger and cargo, (4) long-range international passenger, (5) long-range international cargo, and (6) aeromedical. This research is concerned with the two long-range international segments (passenger and cargo). These two segments accounted for all of the aircraft committed to the Gulf War airlift.

The economic advantage of CRAF derives from two facts. First, acquisition costs (typically, less than one-tenth of the total cost for large carriers) and operating costs, including crew training, are paid by the air carriers. Second, the government only pays for services it actually uses.

For emergencies, the Air Mobility Command (AMC) first draws upon military airlift capabilities not routinely used during daily operations. As needed, such "reserve" capability is augmented by diverting military transports from routine operations. When that proves insufficient, further augmentation is obtained by contracting with interested air carriers participating in the CRAF program. For additional augmentation, the government can progressively activate the three stages of the CRAF program that compel the participating carriers to provide the types and quantities of transports that they had previously agreed to in exchange for the government's routine business that is covered by the CRAF program.

For example, the following CRAF stages were activated or considered for activation for the Gulf War airlift:

- **Stage I.** The Stage I activation by the Commander in Chief of the Military Airlift Command (MAC) in August 1990 gave the Air Force the authority to use the 39 Stage I aircraft (22 cargo) that were then committed.
- **Stage II.** By later activating the cargo aircraft element of Stage II, the Secretary of Defense provided the Air Force with authority to use 16 additional cargo aircraft.
- **Stage III.** By also activating the cargo aircraft element of Stage III, after a declaration of emergency by the President or his designee, the Air Force could have added 103 additional cargo aircraft. Although MAC considered a Stage III activation, it was not done.

What makes CRAF credible is the fact that military and civil transports have complementary strengths that can be called upon to conduct very large-scale airlift operations. This mix of military and civil resources has proved to be fiscally attractive, because it combines

- The speed with which military transports can move large equipment that otherwise must be shipped by surface transportation modes
- The ability of military transports to deliver large rolling stock to sites that are not prepared for receiving such specialized cargo
- The ability of very large civil transports to carry large loads of passengers and baggage over great distances to well-prepared air terminals
- The speed and economic efficiency with which civil transports can move passengers and their baggage.

Measuring Fleet Capacity for Airlift

Finding the right mix of military and civil airlift capabilities requires the use of tools to measure the relative contributions of military and civil sources of airlift. The DoD has used an approach to measuring fleet capacity for airlift that uses aircraft characteristics to estimate the aggregate contributions of different types of aircraft. The aircraft characteristics are stated in terms of the planning factors listed in Table 1.1 for cargo airlift. As Table 1.1 and Figure 1.4 illustrate, this approach also shows the relative contributions of different types of transports to the total assessed capacity.

The total theoretical capacity of 49 million ton-miles per day could be used to deliver 7,000 tons per day from an aerial port of embarkation (APOE) to an aerial port of debarkation (APOD) that was 7,000 n mi away. However, due to materiel-handling con-

Table 1.1

DoD's Traditional Approach to Calculating Intertheater Airlift Capacity

	Air Force Planning Factors that Determine the Daily Airlift Rate					
Aircraft	Average Block Speed[a] (kts)	Average Utilization Rate[b] (hrs/day)	Average Payload (tons/aircraft)	Average Productivity (miles with cargo)/(miles without cargo)	Average Number of Aircraft	Daily Airlift Rate[c] (million ton-miles per day)
Military Transports						
C-5	423	11	68.9	0.47	109	16.4
C-141	410	12.5	27.5	0.47	234	15.5
C-17	440	15.65	48.3	0.47		
Total					343	32
Civil Transports						
Wide body	450	10	74.55	0.47	82	12.9
Narrow body	440	10	36.2	0.47	59	4.4
Total					141	17
			Total military plus civil		484	49

[a]2,500 n mi missions.
[b]For surge conditions.
[c]Rate = speed × utilization × payload × productivity × aircraft.

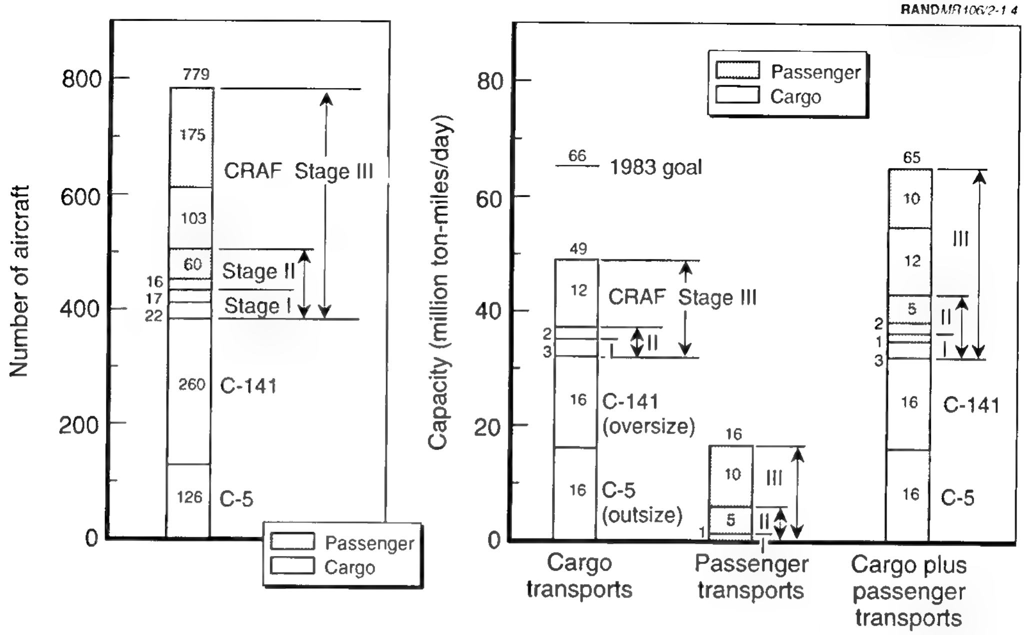

Figure 1.4—Air Force's Assessment of the Total Capacity for Military and Civil Intertheater Airlift During 1992

straints at aerial ports, it would be impractical for a single APOE (or a single APOD) to handle the flow of 484 cargo transports. Thus, realization of the theoretical cargo capacity can be constrained by the availability of airfields and the materiel-handling capabilities at those airfields.

Table 1.1 illustrates DoD's significant dependence upon civil-style transports, particularly wide-body transports, for airlifting cargo. Figure 1.4 adds the civil transports that would be used to airlift passengers. It shows that the CRAF carriers had committed 393 long-range aircraft (Figure 1.4) as of July 1, 1990. The Air Force had a total of 386 C-5 and C-141 transports at that time.[4] As the figure illustrates, activation of CRAF Stage III constitutes a significant increase in the availability of civil-style transport capacity for the DoD.

Figure 1.4 also shows the goal for airlift capacity of 66 million ton-miles per day, which was set forth in the 1983 Airlift Master Plan based upon a 1981 Congressionally Mandated Mobility Study. The 1981 study recommended adding outsize/oversize airlift capacity in the amount of 20 million ton-miles per day to the baseline airlift force for 1986 (46 million ton-miles per day). The goal of 66 million ton-miles per day was never achieved.

[4]Of the Air Force's aircraft, 344 were assigned to operating units at that time. The remainder were in various stages of overhaul, and a few were assigned to introductory training.

APPROACH

The Air Force requested a six-month special project to be conducted during FY 1992 under the direct-assistance provisions of the Project AIR FORCE contract. The approach to the research, including the development of new research tools, evolved through the course of our interactions with the Air Force. Figure 1.5 illustrates how the research was divided into two major phases plus a follow-on phase that addressed the Air Force's further questions.

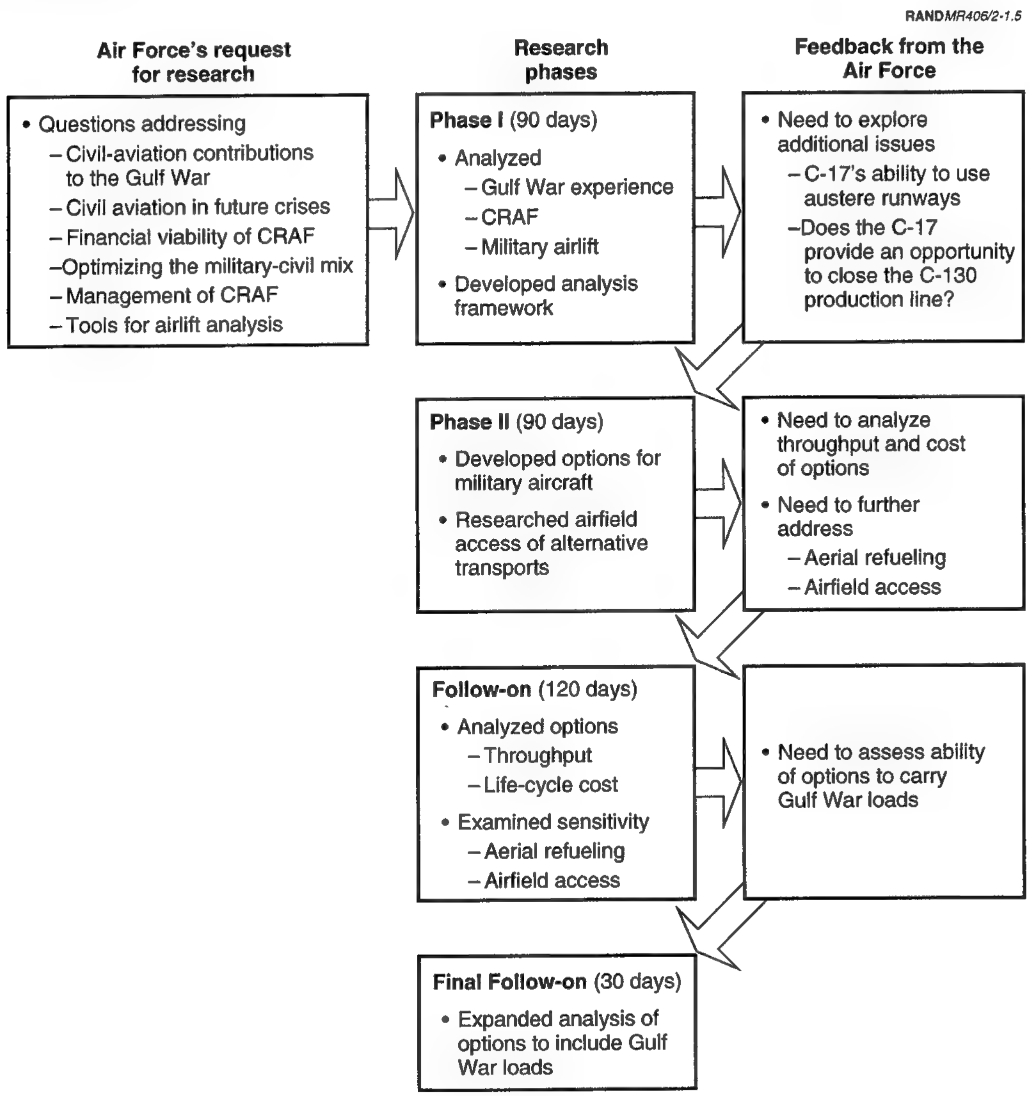

Figure 1.5—Roadmap for the Evolution of the Research

Phase I Research

To build an analytical basis for estimating the right mix, Phase I (Figure 1.6) focused mainly on the Gulf War airlift, background on military airlift, and CRAF.

Civil and Military Airlift Contributions to the Gulf War. Phase I analyzed the implications of the Gulf War for the future development and use of both the civil and themilitary airlift fleets. It analyzed the loads carried by both and the opportunities to improve the efficiency with which these resources were used.

Civil Airlift in Future Crises. To understand how civil aviation might best be employed during future crises, the difficulties encountered in applying CRAF resources during the Gulf War airlift were examined, and the opportunities that CRAF has to continue making uniquely important contributions were assessed.

To try to use CRAF to reduce the life-cycle costs of the C-17, we briefly explored the possibility of leasing C-17 aircraft to CRAF carriers. Aside from the effects that might have on airline unions and insurance, we found an opportunity for only a few C-17s

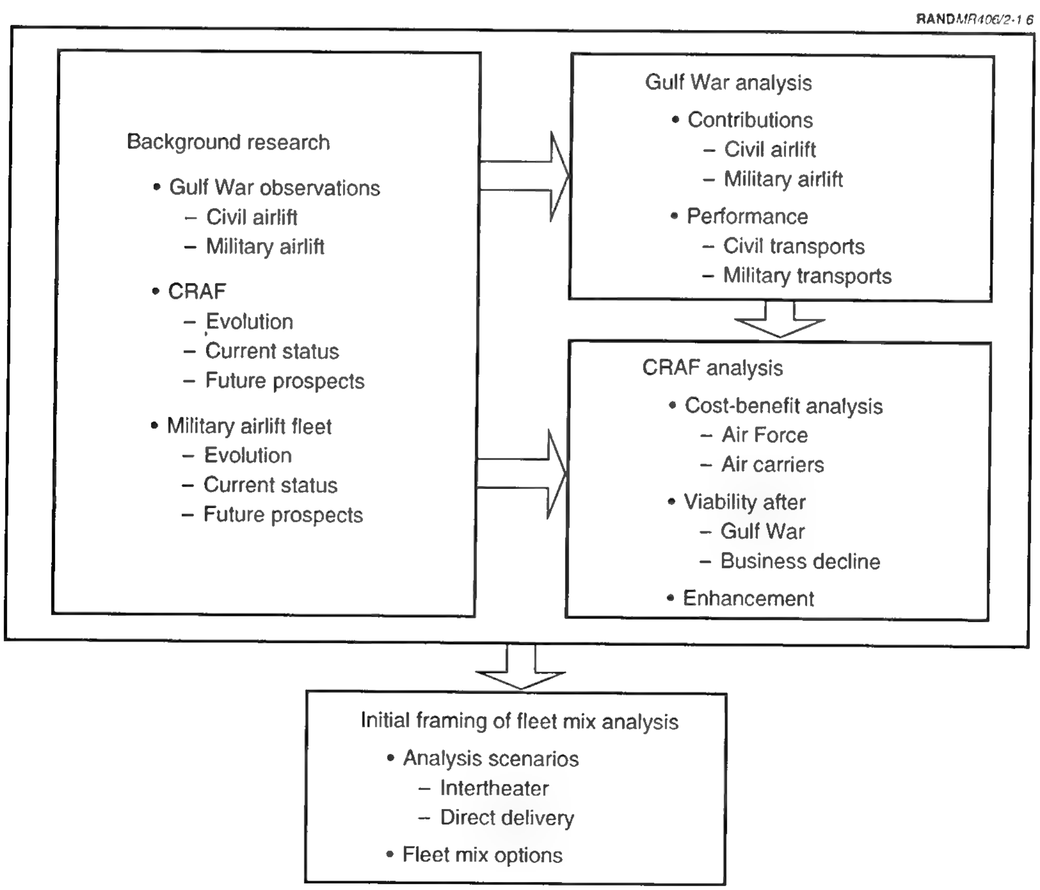

Figure 1.6—Arrangement of Research Activities for Phase I

to be leased. First, the Air Force found that there is only a small demand for its unique capabilities in the private sector. Second, our analysis of air- carrier financial records and the operating and support costs for the C-17 showed that the C-17's other capabilities can be provided at much lower prices by aircraft designed for those purposes. Air Force interviews with air carriers confirmed this assessment.

Financial Viability of CRAF. Phase I also examined issues related to financing airlift capabilities. The concept that there must be excess capacity in peacetime for there to be adequate capacity during wartime was explored by addressing three related fiscal questions: Should the excess capacity be in the civil or military sectors, or both? How much does this excess cost, and how should the Air Force pay for it? Is it cost-effective for the Air Force to make better use of CRAF in peacetime? To address these questions, we developed models and estimates for the total costs of airlift over the 30-year period ending with 1990. We also assessed the current costs of providing airlift services by civil air carriers and by military transports.

Because the financial viability of CRAF is a concern, Phase I also addressed the following questions: Is CRAF a profitable undertaking for the airlines? To what extent is the peacetime/wartime concept of CRAF still valid, given that air carriers may lose money once CRAF is activated? In the event that peacetime business with CRAF carriers is reduced, are there other incentives that would encourage CRAF participation? We also explored the counterbalancing question of whether CRAF is cost-effective for the Air Force. To address these questions, we analyzed the process the Air Force uses to set the rates that are paid to CRAF carriers for the services they provide. We also analyzed the costs that carriers of different sizes and types incur in providing such services during both routine periods and during an activation of CRAF. We explored the possibilities for improving incentives, and we examined the cost-effectiveness of CRAF from the Air Force's vantage point by modeling and estimating the costs of providing airlift services both by CRAF and by military airlift over a 30-year period.

Management of CRAF. Finally, Phase I examined the possibility of improving the efficiency of CRAF management during an activation by addressing the following questions: Should the Air Force eliminate or modify the activation system (Stages I, II, and III)? Should the stages of CRAF activation be tied to modules or scenarios? What is the appropriate level of control on the daily and emergency operation of the future CRAF fleet? How should CRAF be managed: by tail number regardless of ownership or by individual airline contract? To address these questions, we examined the experience of the Gulf War airlift, the concerns of the large air carriers who supply most of the Stage III aircraft, the possibilities of improving the incentives for the large air carriers to support CRAF, and the costs that air carriers would see in tighter control of CRAF. It soon became apparent that tighter control in the form of tail-number management and making CRAF activation automatic for specific scenarios would work against efforts to recruit participation in CRAF.

Research Plan for Phase II. The final product from Phase I was the initial research plan for Phase II. The plan initially called for examination of two airlift scenarios: an intertheater deployment from the United States to Southwest Asia and a direct-delivery deployment to austere airfields in an area remote from seaports. The

premise underlying the latter deployment was that only the C-17 could access the austere airfields.

Our briefing of the Phase I results and the Phase II research plan produced concerns about our planned approach to analyzing alternative military transports. The most serious concern questioned the number of times that C-17 transports would be able to land on a runway at an austere airfield before the runway would no longer be usable because of wear.

The briefing also resulted in an additional question about continuing the C-130 production line. If additional intratheater airlift resources were needed at some future time to replace aging C-130s, could not additional C-17s be purchased instead and meanwhile forgo the expense of maintaining the C-130 production line?

Phase II and Follow-On Research

Phase II and follow-on efforts concentrated on military airlift options. To meet the analytical needs of the Phase II research, we pursued a broad set of related research activities, depicted in Figure 1.7. Fortunately, with the significant assistance of the Air Force, the data-collection efforts of Phase I provided a good basis for the development of the Phase II analytical tools.

When the Phase II results were briefed to the Air Force at the six-month point, the Air Force asked for further research to address (1) throughput and costs for alternative

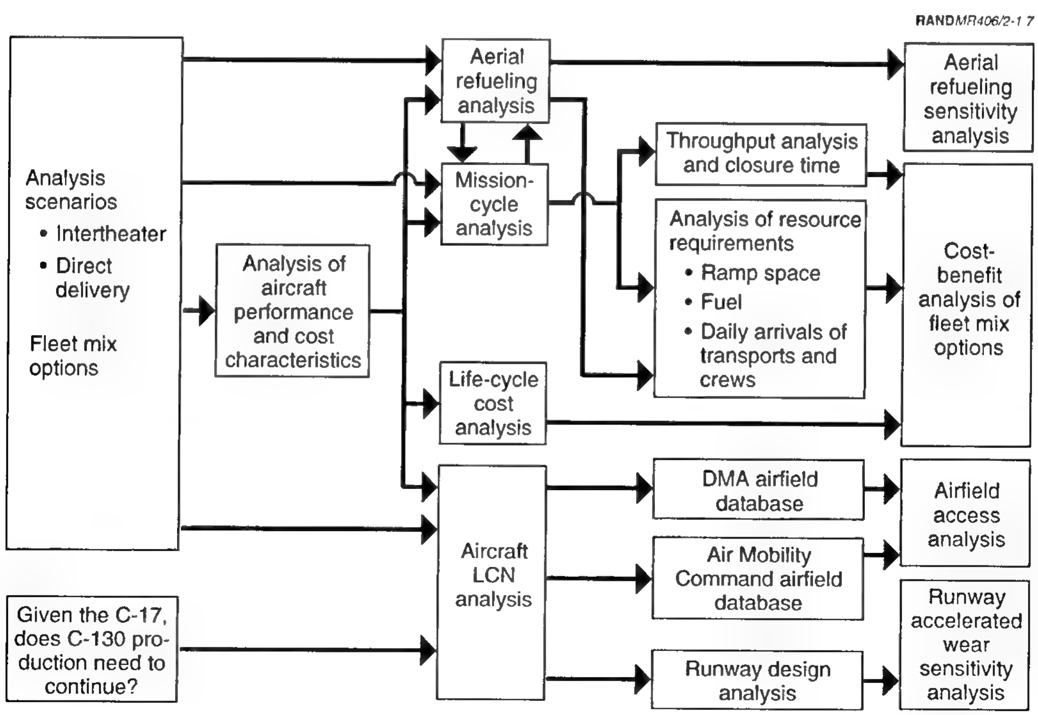

Figure 1.7—Arrangement of Research Activities for Phase II and the Follow-On Phases

military airlift fleets, (2) costs and benefits of aerial refueling, and (3) issues that had arisen from the work on airfield access of alternative transports. Four months later, these follow-on results were briefed to the Air Force. That briefing yielded a further request to explore the ability of alternative airlift fleets to airlift the mix of loads that were airlifted during three 30-day periods of the Gulf War. Those final research results were provided as fiscal year 1992 drew to a close.

The approach to the Phase II and the follow-on research was divided into three principal parts dealing with the airlift system and its infrastructure, life-cycle costs, and airfield access.

Analysis of Airlift System Performance and Its Infrastructure Requirements. Following an airlift analysis practice developed at the AMC (Merrill, 1991), we made extensive use of spreadsheet models to perform most of our analysis. The concepts in AMC's Airlift (mission) Cycle Analysis Spreadsheet (ACAS) formed the backbone of our throughput and aerial refueling analyses.[5] Our research made three conceptual advances:

- **Modeling of aerial refueling.** An advantage of in-flight refueling is the elimination of stops at en route airfields. Eliminating stops means fewer opportunities for aircraft to break during the landing and takeoff, which cause many of the maintenance problems that end up delaying aircraft. Eliminating stops also reduces time spent refueling (in flight is faster) and eliminates time waiting for taxi, ground servicing, and waiting for release for takeoff. The modeling of the aerial refueling process accounted for availability of flight crews; limits on flight-crew flying time; characteristics of the operating bases that the tankers would use (the typical lengths of the runways and the typical altitudes); the fuel-carrying capacity of the tankers; and the fuel that the tankers would consume in meeting the transports, conducting in-flight refueling, and returning to their operating base.
- **Modeling utilization of transport aircraft.** This is a very significant factor, because the calculated throughput capacity is proportional to the assumed utilization rate for a transport (see Table 1.1). Because the goal for the C-17's utilization rate (15.65 hours per day) has been so high in contrast to the goals for other military transports (12.5 for the C-141 and 11 for the C-5), we chose to model the utilization process rather than assume a utilization rate. The model considers average flying time between specific bases, which varied with the distance between the bases, slowing down for aerial refueling, ground refueling, the breaking and repair of aircraft, loading and unloading of aircraft, and delays for weather and air traffic based upon the experience of the Gulf War.[6]
- **Modeling of infrastructure requirements.** Assessing the comparative needs of alternative airlift fleets for infrastructure resources is important, because the usable amount of airlift can be constrained by limitations on resources, such as air crews, ramp space, fuel, crew rest facilities, and equipment and personnel for

[5]See Merrill (1991) for a description of the ACAS.

[6]The model was implemented with a spreadsheet that accounted for the time and distance associated with each leg of a mission and each ground stop.

servicing of aircraft. Thus, each of these resource categories was modeled and included in the comparison of alternative fleets.

The modeling of aerial refueling, aircraft utilization, and needs for infrastructure resources was supported by a series of models that were developed for this research.[7] A mission-cycle model was developed to analyze airlift system performance and infrastructure needs for each mission considered in the analysis. A fleet performance and infrastructure model was developed to aggregate the results of individual missions. An option performance and infrastructure model was developed to aggregate the results for the fleets comprising each option (or base case).

Analysis of Life-Cycle Costs. Analytic tools were also developed and applied to assess life-cycle costs (see Chapter Four for details). The life-cycle cost analysis drew heavily upon the Air Force's SABLE model for estimating operation and support costs for individual squadrons for each type of transport.[8] Acquisition costs generally came from the Selected Acquisition Reports (SARs).

A fleet life-cycle cost model was developed to take the squadron operation and support costs plus future acquisition costs and compute life-cycle costs for various discount rates (none, 5 percent, and 10 percent). Next, an option life-cycle cost model was developed and used to combine the costs of the fleets comprising the option (or base case) of interest.

Analysis of Airfield Access. Analytic tools were developed and applied to assess (1) the weight-distribution characteristics of alternative transports when they use a runway, (2) the weight-bearing capacity of different types of runways when they are used by the transports of interest, (3) the relative numbers of airfields with runways suitable for normal use by each type of transport, and (4) the additional numbers of runways that transports might use on an emergency basis when stresses in runways might be allowed to exceed the normal standards that are set to avert accelerated wear and early need for repair. (See Chapter Five for details.)

The weight-distribution characteristics of aircraft and the weight-bearing characteristics of runways were analyzed using the load classification number (LCN) concept. The aircraft LCN analyses used the Portland Cement Association computer model for designing concrete pavements,[9] and the influence factor method for asphalt runways (see Pereira, 1977). To assess the potential consequences of operating transports on very weak runways, we used these same methods for concrete and asphalt runways to design a variety of weak runways, which we then tested analytically by exposing them to simulated use by the transports of interest. See Chapter Five for these results.

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[7]Chapter Four provides further details about these models and their use in the analysis.

[8]See Systematic Approach to Better Long-Range Estimating (SABLE) Model Hand Book for Aircraft Operating and Support (O&S) Cost Typicals. This computer database is maintained by Headquarters USAF, Comptroller Systems Support.

[9]See Portland Cement Association, undated.

The advancement in analytic tools in these three areas (airlift system and infrastructure, life-cycle costs, and airfield access) gave us the capability to broadly assess the pros and cons of alternative airlift fleets in terms of both capabilities and costs.

ORGANIZATION OF REPORT

Airlift's experience supporting the Gulf War shows that the demand for airlift is changing (Chapter Two). Understanding such shifts in demand is key to finding the right mix of military and civil airlift for future needs. Insights that the large air carriers have drawn from the Gulf War have raised concerns about the future role of civil airlift. Chapter Three examines the changing supply of civil airlift by exploring changes in civil fleets and the long-term viability of CRAF. It also explores the value of CRAF and ideas for sustaining its viability. On the military side of the civil-military mix, Chapter Four examines the need for the supply of military airlift to change. A major issue affecting the supply is the comparative capabilities of transports to access the world's airfields. Chapter Five explores that issue. Chapter Six presents our conclusions.

THE DEMAND FOR AIRLIFT IS CHANGING

From the founding of the Air Transport Command in 1942 to the operations of today's AMC, airlift missions have satisfied the demands of their times because the Army Air Corps and then the Air Force continued to evolve a mix of capabilities to carry anything, anywhere, anytime.[1] Over this period, the level and composition of the demands have undergone tremendous changes as national needs and technology have evolved in ways that could not have been imagined in 1942. It is only prudent to assume that needs and technology will continue to influence the demands for airlift over the next 25 years. Although we cannot begin to imagine the full spectrum of relevant changes, we can work to understand the changes that have occurred to date, the trends that seem to be in place, and the sensitivity of those trends to plausible future events. See Figure 2.1 for a guide to this chapter.

SIGNS OF CHANGE ARE DEEPLY ROOTED

The DoD's current reliance on both civil and military airlift to meet surges in demand has two principal historical roots. The demand for military airlift, as we currently know it, has its roots in the experiences of World War II. The DoD's demand for civil airlift is a consequence of the Berlin airlift and the struggle of U.S. airlines in establishing their international market positions during the late 1940s and the early 1950s. Most recently, the Gulf War experience and changing world circumstances suggest it is time to rethink how the changing demand for airlift needs to be better reflected in the DoD's supply of civil and military airlift.

As Dangers for Transports Lessened, Demand for Civil Airlift Grew

The Burma Hump Airlift Was a Very Costly Military Operation. During 1942, when the civil sector could not keep pace with the need to airlift materiel from India to China by flying over the Burma Hump, the Army Air Corps increased its acquisition of the C-47, a militarized version of the civil-style DC-3 transport, to meet the needs

[1]This characterization of airlift was set forth by General William H. Tunner, former Military Air Transport Service Commander; see U.S. Air Force (1991a).

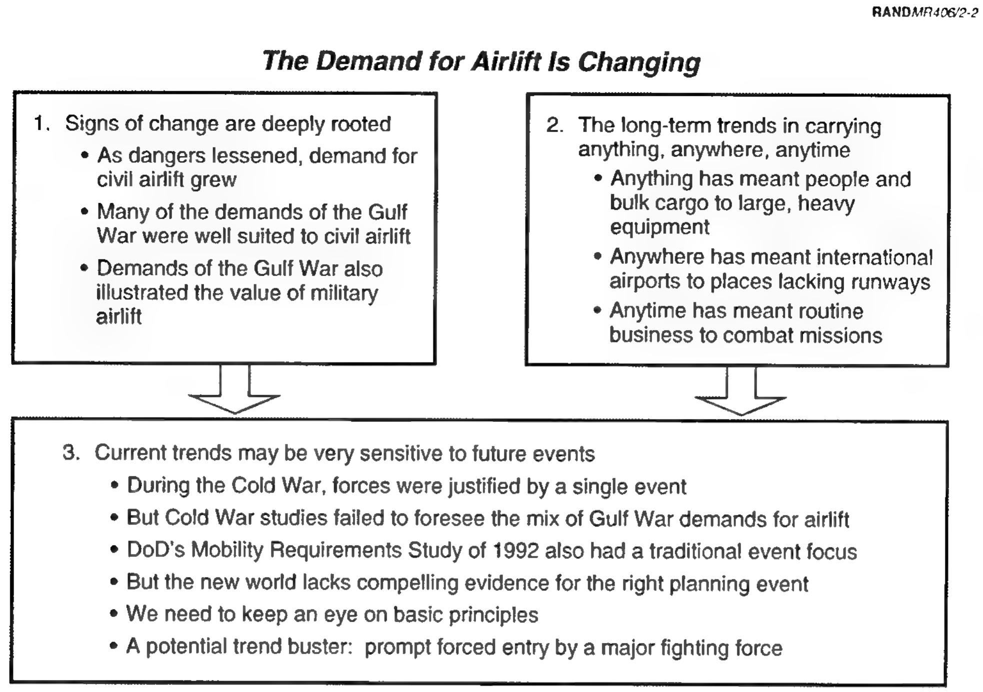

Figure 2.1—Flowchart for Chapter Two

of the three-year airlift operation over the Burma Hump.[2] The airlift was a very dangerous operation that led to the loss of 792 crew members and 460 transports, while delivering a total tonnage comparable to that which was airlifted for the Gulf War (Figure 2.2). The dangers in the Burma Hump Airlift were enemy action and dangerous flying conditions that included mountains, bad weather, and sometimes faulty navigational equipment. The Burma Hump Airlift demonstrated that the military can order its crews to take their transports anywhere, anytime that the nation's needs dictate. Because civil air carriers cannot compel their employees to take their transports into harm's way, a fundamental distinction between military and civil airlift has been the ability of the military to control, and to have full confidence in their ability to control, the operation of military airlift.

The Berlin Airlift's Demands on Civil Airlift Contributed to the Founding of CRAF. During 1948, when military airlift capacity needed to be augmented, the United States and its allies turned to their civil air carriers for assistance.[3] Following the

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[2]During the first two months after the military airlift started, the civil air carrier (a company that Pan Am partly owned) flew 112 missions, and the Air Transport Command flew 196 missions. Thereafter, most flights were flown by the Air Transport Command (U.S. Air Force, 1991a).

[3]To enable the Military Air Transport Service to use more of its military transports for the Berlin Airlift, while also meeting its other air transportation commitments, the government contracted with civil air carriers to provide transportation services across the Atlantic that previously had been provided by military transports (U.S. Air Force, 1991a).

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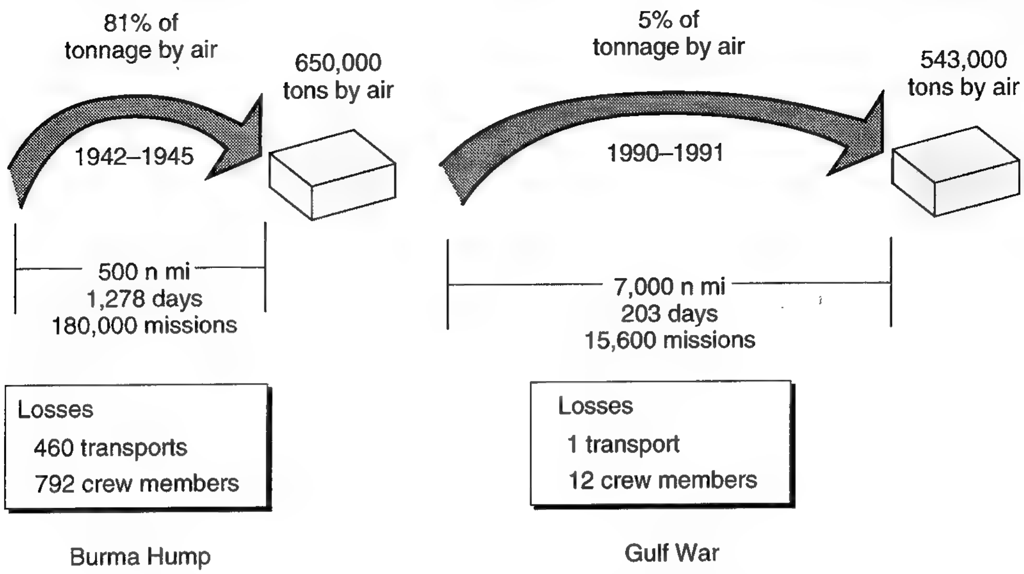
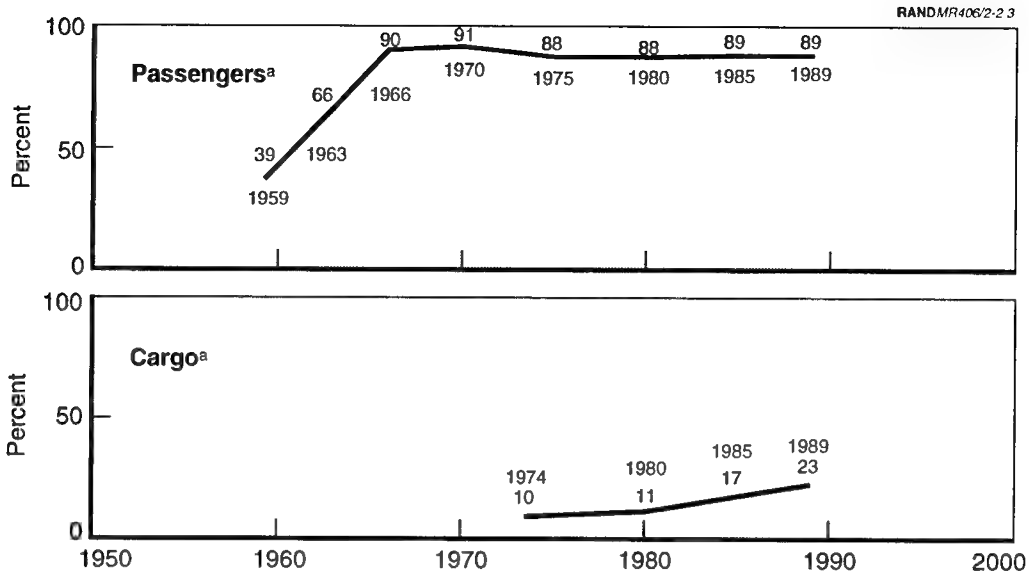


Figure 2.2—The Changing Nature of Airlift from Burma to the Gulf War

airlift, the civil air carriers continued their lobbying of the Congress and the White House to obtain a share of the DoD's peacetime airlift business, which then was exclusively provided by the Air Force's Military Air Transport Service (MATS), the predecessor to MAC. After several years of debate, CRAF was established in 1952. Several years later, it was agreed that MATS would give the DoD's international passenger business mostly to the civil air carriers and that the Air Force would use its transports mostly for carrying materiel during peacetime. Thus, as Figure 2.3 shows, passenger business was shifted from MATS to civil transports during the late 1950s and 1960s. Further procurement of aircraft by MATS and its successor organization would concentrate on a style of airplane optimized for moving military equipment rather than passengers.

The Cold War's High Demands for Airlift Made CRAF an Economic Necessity. Reinforcing NATO against an impending attack by the Warsaw Pact and the Soviet Union would have required the civil air carriers to provide tremendous augmentation of military airlift capabilities. Although CRAF was never activated for the purpose of defending our European allies, the extraordinary size of the demand made CRAF an economic necessity. The mission of deterring or containing a major conflict in Europe was of paramount importance to averting a nuclear conflict. The need to enlist civil air carriers to be prepared to assist was compelling. Although deterring conflict in Europe was of paramount importance, few expected that CRAF would ever actually be activated.

The Gulf War Airlift Demonstrated That the Demand for a CRAF Was Real. By the time the Gulf War demonstrated that the demand for a CRAF was real, the nature of the demand for airlift had changed drastically from the days of the Burma Hump



[a]Channel operations. Does not include exercises and special assigned airlift missions.

NOTE: 1991 budget for augmentation: $345M for passengers + $73M for cargo = a total of $418M.

Figure 2.3—Percentage of Routine Airlift Provided by Civil Augmentation

Airlift.[4] The size, range, speed, and cost of transports had all increased in very significant ways. The dangerous nature of the mission had also changed. With the rising cost and shrinking numbers of military transports, there has come the realization that it is militarily unacceptable, except under the most dire of circumstances, to risk loosing a military transport that costs as much as a C-5. The order of magnitude growth in the capabilities (and costs) of military transports has fundamentally altered the nature of their application. The smaller and much less expensive C-130 (about a fifth the cost of a C-5) is far more likely to be found in semihostile airspace than a large transport like the C-5.[5]

Many of the Demands of the Gulf War Were Well Suited to Civil Airlift

Of the equipment and supplies that transport aircraft carried to the Persian Gulf during the six months of the airlift, Figure 2.4 shows that only one-third of the material (by weight) was ill suited for CRAF's civil-style transports, because it did not fall

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[4]The Burma Hump Airlift, one of the main applications of intercontinental transports during World War II, would actually be viewed today as a tactical airlift operation because of the relatively short distance that was flown.

[5]The aggressive application of the C-130 and the cautious use of the C-5 during the Vietnam War is a good illustration of this point. See Eichhorst (1991, Chapter 4) and U.S. Air Force (1991a, Chapter V).

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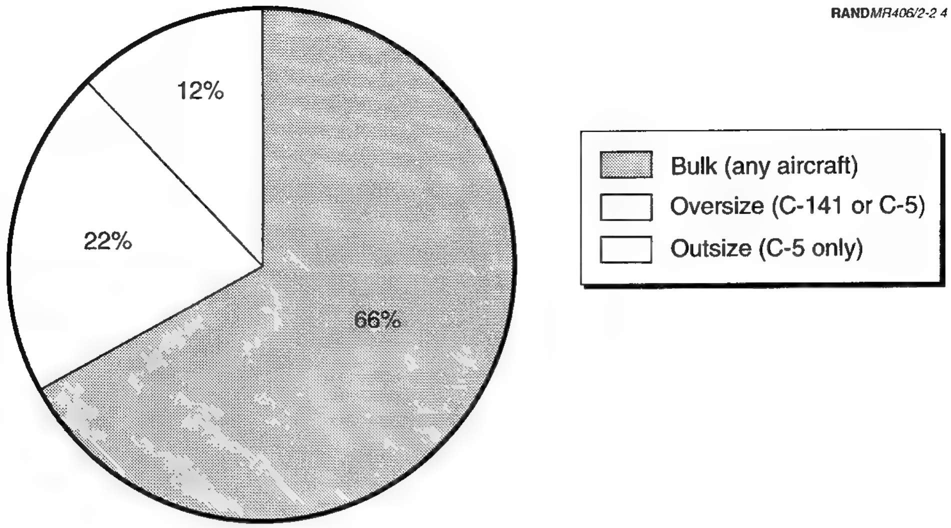

Figure 2.4—Types of Cargo Moved During the Airlift for the Gulf War by Military and Civil Airlift (August 1990–February 1991)

in the bulk cargo category.[6] Although about 40 percent of CRAF's Stage II cargo capacity is rated as capable of carrying oversize materiel, as a practical matter it is difficult to use it for that purpose, because floor strengths vary by air carrier and aircraft.

Even during the first month of the airlift, the Air Force estimates that half of the cargo shipped to the Gulf was bulk and one-tenth was outsize (Figure 2.5).[7] During the airlift's two peak months of January and February, bulk cargo accounted for two-thirds of the materiel and outsize for one-twelfth.[8] The large amount of bulk and modest amount of outsize is one of the most significant insights from the Gulf War experience relative to finding the right mix of military and civil airlift for future needs, because outsize cargo requires the application of premium resources (the C-5 or the C-17).[9]

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[6]The material for this section was provided by the headquarters staff at the AMC in response to specific requests for information. Some of that material is included in Ewing (1991). The works of Chenoweth (1993), Lund, Berg, and Replogle (1993), and Bowie (1993) were helpful in framing the requests for data.

[7]The assessments in Figures 2.4 and 2.5 came from different analyses by the Air Mobility Command. Because comparison of the percentages (such as for outsize) reveals some inconsistencies, the presented results are only approximate.

[8]Such averages do not address the question of whether all time-critical demands for outsize capability were satisfied quickly. Lund, Berg, and Replogle (1993) show that the missions scheduled for the C-5 exceeded the available aircraft on several occasions (p. 56). This created the impression that the Air Force had exceeded its capacity for outsize airlift. During the cited periods, however, C-5s were being used to move oversize and bulk cargo as well as outsize. This raises issues about the DoD's ability to command and control the application of the airlift system in a way that matches transport capabilities and the needs of particular loads.

[9]The word "premium" is used in the present context because it costs more to ship a ton of outsize cargo than a ton of bulk cargo. This point will be discussed further in Chapter Four. Other interesting periods to have examined would have been August 7 to 15 and January 15 to 25. However, due to data base limitations, the Air Force lacks visibility on specific loads. Consequently it has had to reconstruct broad esti-

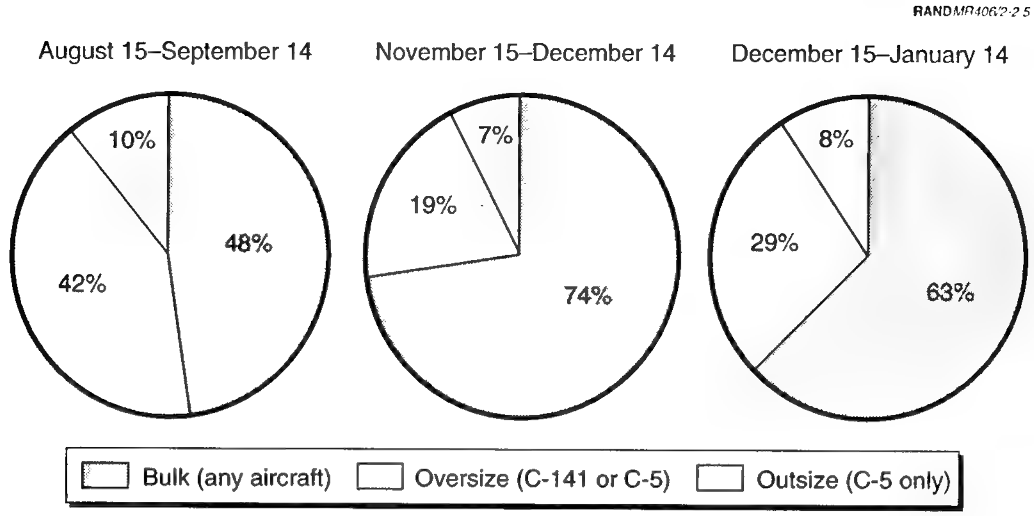

Figure 2.5—Estimated Mix of Gulf War Cargo Loads for Three 30-Day Periods

Some researchers dismiss the Gulf War experience, because a lot of bulk cargo was never used for the war effort, and because bulk cargo includes materiel that can be prepositioned and delivered by sealift. They believe that much of the bulk cargo either should not have been sent at all or should not have been delivered by airlift.

Although bulk cargo includes such commodities as food and all sorts of replenishment supplies, it also includes any materiel transported on a 463L pallet. Any item of materiel that is less than 8.6 ft long, 7 ft wide, and 7.8 ft tall fits the category known as bulk cargo. This includes all sorts of equipment, munitions, and supplies critical to the performance of combat units. Because most of what was delivered by airlift fit on the 463L pallet, most of the deliveries fell in the bulk cargo category.

Regarding pallets of materiel that proved unnecessary for the war effort, there probably are opportunities for improved command, control, and communication of what is needed. Opportunities for making such improvements should be pursued, and airlift needs should be reassessed as progress is made. Without some evidence of the extent of the opportunity for improvement, and without some concept for implementation, it seems premature meanwhile to dismiss the Gulf War experience.

Significant Demands Were Placed upon Civil-Style Transports. During the Gulf War airlift, AMC augmented its fleet of 109 primary assigned aircraft (PAA) C-5 and 234 PAA C-141 transports by using 38 aircraft from CRAF during the first four months and then finally increasing that number to 96 during January and 110 in February. Half of the 110 were volunteered above and beyond what was required under the CRAF Stage II activation requirements that took effect on January 17, 1991. Although AMC

mates of load breakdowns. At the time of the research, estimates were not available for these additional periods.

needed additional civil-style wide-body transports during January of 1991, that demand could not be satisfied. There were no more wide-body freighter-configured transports that the civil air carriers were willing to provide on a voluntary basis. Moreover, the government chose not to activate the third stage of CRAF that would have compelled air carriers to provide the needed civil transports. Instead the U.S. Transportation Command elected to use a combination of sealift and military air transports to carry bulk cargo. The military transports, however, proved most useful at moving vehicles and equipment.

Throughout the Gulf War airlift, the civil transports played a significant role in airlifting two-thirds of the passengers and one-fifth of the cargo (Figure 2.6). Cargo-configured models of the civil transports proved to be most useful in moving bulk cargo, chiefly from AMC's channel ports at Dover AFB and Charleston AFB. To depict the relative contributions of military and civil airlift to support of the Gulf War effort, Figure 2.6 presents the relative contributions in terms of cargo ton-miles for the six-month period, as well as for the peak month (January 1991). The figure presents similar data for the movement of passengers. The figure uses passenger-miles and ton-miles instead of passengers and tons delivered to account for the differences between moving people and materiel from the United States to the Gulf versus from Europe to the Gulf. For example, for the period represented in the figure, 91 percent

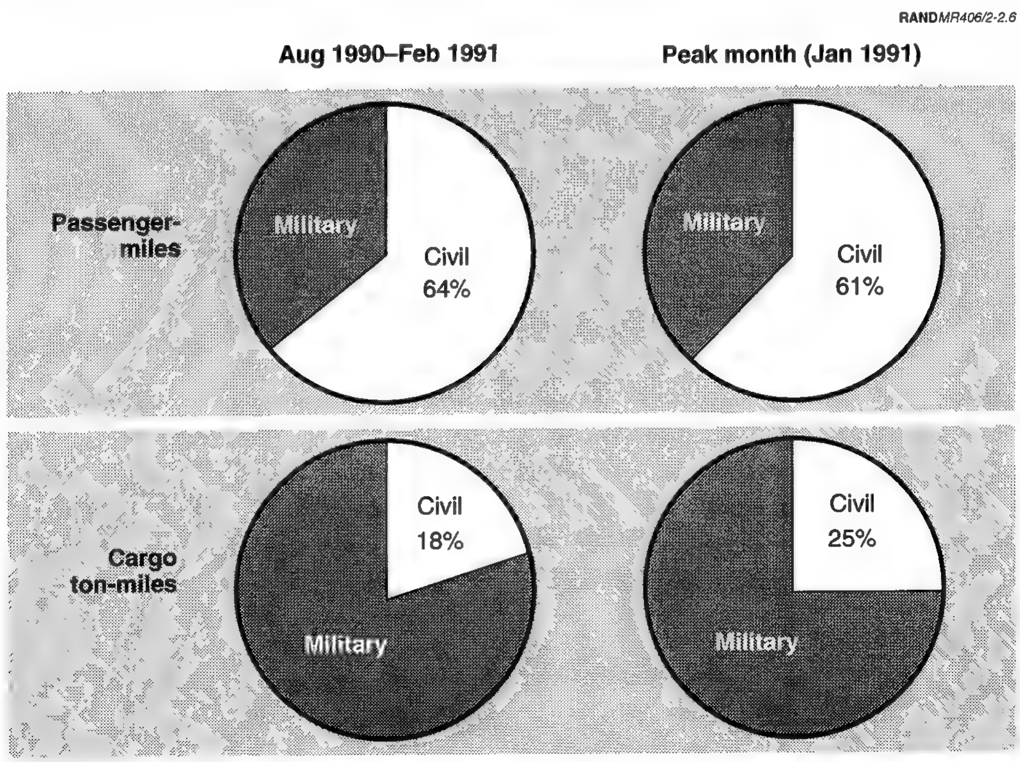

Figure 2.6—Civil Airlift Augmentation Was Significant for Passengers and Cargo for Gulf War Missions

of the civil airlift missions started in the United States, whereas only 73 percent of the military airlift missions started in the United States. Most of the remainder started in Europe.

Although civil airlift accounted for two-thirds of the passenger miles, this was appreciably less than the 90-percent planning factor that had been used prior to the Gulf War experience. Reasons for this shortfall included constraints on the scheduling of transports that arose when units required that transports fly together to keep personnel and equipment together. The civil transports used civil airfields for en route stops, whereas the military transports used military airfields. Further, during part of the deployment phase the civil and military transports landed at different APODs.

Because two-thirds of the cargo moved to the Gulf was in the form of bulk, the cargo-carrying civil transports had ample opportunity to contribute. Due to their limited numbers, however, the civil transports could only move about one-third of the bulk cargo. During this period civil transports also provided AMC with other worldwide airlift services normally provided by the military transports.

The 747 Was the Most Demanded Civil Transport. A snapshot of the civil transports supporting the Gulf War on January 20, 1991, shows the 747 playing a dominant role (Figure 2.7), both in terms of the number of aircraft involved and their equivalent daily airlift rate in ton-miles per day.[10] Of the ton-miles per day being provided by the civil transports, the 747s accounted for two-thirds.

Although the older models of the 747, the -100 and the -200, that were used in support of the Gulf War have less capability than the most recent version (the -400), their planning factor loads are nonetheless 50 percent greater than those for the C-5 for the nominal distances (3,500 n mi critical leg) involved in a deployment to Southwest Asia.[11]

The Demands of the Gulf War Also Illustrated Value of Military Airlift

Military transports demonstrated two significant advantages over civilian transports: (1) vehicles and equipment were rolled on and off the transports with minimal materiel-handling equipment and personnel, and (2) military transports continued to operate during a hostile period, while for a few days some civil air carriers stopped operations.

Although the civil fleet was a major contributor in the movement of passengers and bulk cargo, the military fleet in contrast was a major contributor in the movement of vehicles and equipment that are either impossible or difficult to load on civil transports. Most particularly, during the early weeks of the deployment, the military fleet moved the 82nd Airborne Division's equipment and vehicles to establish an early and significant presence in the Gulf.

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[10] To calculate the equivalent daily airlift rate, we converted passengers to pounds assuming 300 lbs per passenger (including baggage).

[11] The payload in Table 1.1 for wide-body transports is for a mix of DC-10 and 747 models.

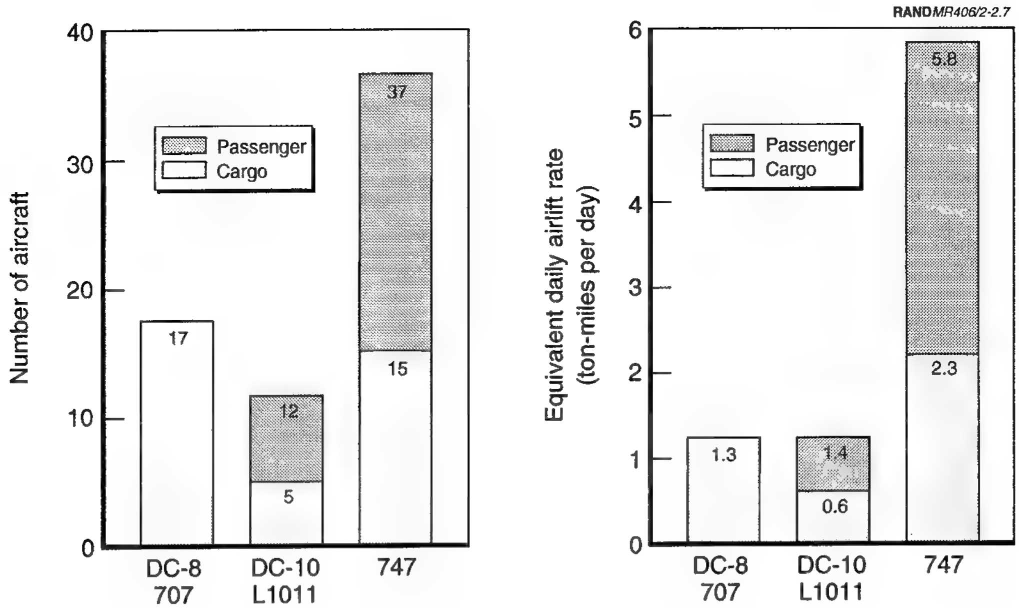

Figure 2.7—Civil Transports Supporting the Gulf War on January 20, 1991

Moreover, during the Iraqi Scud attacks, the rapid deployment of Patriot batteries by military transports to Israel, Turkey, and Saudi Arabia made a significant contribution at a crucial juncture.

THE LONG-TERM TRENDS IN CARRYING ANYTHING, ANYWHERE, ANYTIME

Understanding what airlift capability is needed and articulating that need are daunting tasks, because the complexion of threats is shifting from a few known locations to a truly global scale with the proliferation of modern weapons of war.

The current military airlift fleet and its complementary CRAF were designed and sized to support a massive deployment of ground and air forces to Europe to wage a conventional war against the combined forces of the Soviet Union and the Warsaw Pact and, in so doing, avoid global thermonuclear warfare.

Depending upon the final depth of the drawdown in overseas presence, and the nature and location of U.S. interests and commitments overseas, it is possible that the need for very rapid airlift might actually increase the amount of airlift resources that are needed. On the other hand, the need for airlift may decline, and substantially so as the United States goes through a readjustment of its defense priorities to meet the twin challenges of budget pressures and a changed threat. Resulting changes in national strategy and force structure, including reduced presence of forces overseas, are altering both the amount and nature of the airlift capabilities that are needed.

Anything Has Meant People and Bulk Cargo to Large, Heavy Equipment

Especially during the earliest years of airlift, the 1940s and the early 1950s, much of what was carried was either bulk cargo or people, because the early transports were modified versions of civil-style transports that had been optimized for carrying people. The need to provide reinforcement units for a large ground war in Europe shifted the demands to a heavier concentration on moving oversize and outsize equipment for combat units. Accordingly, the true military-style transport emerged with the designs of the C-130, C-141, and C-5, all of which featured self-contained loading ramps and high wings that place cargo floors close to the ground to facilitate the loading and unloading of heavy equipment at airfields that do not need to have in-place materiel-handling equipment.

During the 1960s and the 1970s, the perceived shortfall in capability to move combat equipment was so great that attention almost exclusively focused on building up the nation's capacity to move equipment for combat units. To reinforce NATO, people would be carried mostly by civil transports. Bulk cargo needs would be satisfied by a combination of host-nation support, sealift, civil air carriers, and the military-style transport.

The mix of loads moved by the Gulf War airlift was very different from that which had been planned for reinforcing NATO because of the combined effects of several factors:

- Limitations on host-nation support.
- The longer times required to move materiel by sea led to decisions to move time-urgent bulk cargo by airlift
- Prepositioning of some unit equipment in the area of the conflict
- Limitations on U.S. airlift capacity, leading to the decision to use sealift to move the Army's units with the heaviest equipment (such equipment accounts for most of the DoD's outsize equipment).

In combination, these factors fundamentally changed the demands for airlift.

The airlift needs for future major regional contingencies will probably include significant amounts of bulk cargo.

Anywhere Has Meant International Airports to Places Lacking Runways

In the early years, airfields were not nearly so plentiful, so airlift often meant building airfields to support operations into such places as Burma and islands in the Pacific. Accordingly, the designs of the C-130 and the C-5 featured capabilities to operate on short (e.g., 5,000-ft–long), unpaved landing strips. Although the C-130 has proved very successful at such operations, the C-5 is restricted from operating on unpaved surfaces.[12] With the development of airfields with paved runways in Europe, many

[12]The C-5's experience is discussed in Chapter Five.

with strong concrete surfaces, the C-5's need for paved runways has not proved to be a serious operational impediment.

Because a very substantial set of airfields had been built in Saudi Arabia, there was no lack of suitable airfields, although the allocation of airfields to accommodate a smooth airlift operation was problematic, as is illustrated in Chapter Four.

The Gulf War demonstrated how a mix of airfields, with varying ground-support facilities, can be used to receive a major airlift operation. The airfields employed ranged from international airports with existing capabilities to receive civil-style transports to military installations that were best reached with military-style transports that had minimal ground-support needs.

With the worldwide growth in airfields and their ground-support capabilities, the demands on airlift have shifted from the situation of having to build airfields or operate on unpaved strips to a situation where it is reasonable to expect that there will be a mix of airfields available within a region that will be allocated to receive a major airlift operation. Although the capabilities of the airfields will vary, it seems plausible to believe that, by matching airfield capabilities and the needs of the transports, a mixed fleet of transports should be able to conduct a major airlift operation, such as was accomplished for the Gulf War.

The airfields available to support future major regional contingencies show no signs of reversing this shift in the mix of airfields away from austere airfields to a mix of airfields including international airports.

Anytime Has Meant Routine Business to Combat Missions

At the end of World War II, MATS continued a reduced level of operations, mainly in support of U.S. forces that remained stationed overseas. *Anytime* thus continues to mean both support for routine peacetime business of the military services and providing a broad range of emergency responses that run from relief missions to a major regional contingency.

During the early years, though, *anytime* also could mean life-threatening missions. Today that is much less the case, because the transports have become so capable and so few that any loss is an almost unacceptable degradation of the nation's airlift capacity. That is not to say that the environment is free of threats. Indeed, today's threats are more diverse and lethal. What has changed is that losses of strategic airlift transports due to hostile action are much less tolerable than they were in the early years of airlift.

Although anytime still means both war and peace, it no longer means going into the kind of life-threatening situations that initially were so common during the early years of airlift.

CURRENT TRENDS MAY BE VERY SENSITIVE TO FUTURE EVENTS

Might something happen that could change the trends we have observed and alter the right mix? The chief concern is that planning continues to be dominated by considerations of a single event,[13] whether it be reinforcing NATO, a Southwest Asia major regional contingency, or two nearly simultaneous contingencies.

During the Cold War, Forces Were Justified by a Single Event

During the Cold War, it was easy to perform analyses of airlift requirements and capabilities relative to specific threats and thereby develop rationales for particular sizes of forces and mixes of capabilities. Such threat-driven analyses provided both a real-world context for research and a recognizable basis for justifying expenditures to maintain calculated levels and mixes of capabilities.[14]

The reinforcement of allied forces in Europe to turn back an attack by the combined forces of the Warsaw Pact and the Soviet Union provided an analytical framework and a justification for investing $39 billion (1992 dollars) in the research, development, and production of 281 C-141 transports and 131 C-5 transports. As the affordability issue ultimately limited the number of military transports, the previously unfilled need for airlift for the European scenario was partially met by establishing a 400-aircraft CRAF that would augment the strategic airlift capabilities of the C-141 and C-5 fleets.

So powerful was the European scenario that "lesser" contingencies, such as a major deployment to the Middle East, were viewed as lacking in stress and lacking in ability to justify major investments in military transports. Through the 1960s and the 1970s, the European scenario was accepted as the dominant scenario based upon the postulate that what will lick the cat will lick the kitten. That is, all other situations could be handled by a fleet designed to satisfy the needs of the European scenario.

When the C-141 and the C-5 entered development during the 1960s, there were no serious forecasts of a Middle East nation developing an armed force of the size, capabilities, and intentions of those that emerged in Iraq.

But Cold War Studies Failed to Foresee the Mix of Gulf War Demands for Airlift

The Congressionally Mandated Mobility Study of 1981 Focused on the Soviet Threat. The study steering group, chaired by the Deputy Secretary of Defense, included representatives from all services, the Joint Staff, and the Office of the

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[13]Or pair of nearly simultaneous events, as is reflected in more recent planning.

[14]Although other potential applications of airlift were also considered, the core rationale for justifying the level of expenditures on airlift was the size of the prospective task of reinforcing NATO. However, the level of airlift capacity never reached the levels that would have been needed to support the war plan. Thus, although intentions were focused on NATO, the size of the airlift fleet that emerged was actually better suited for a smaller airlift task, such as that produced by the Gulf War.

Secretary of Defense. The study focused on several different scenarios, most involving hypothetical Soviet invasions during 1986: invasions of NATO, Saudi Arabia, Iran, and Saudi Arabia followed by an invasion of NATO.

Combinations of several measures were examined:

- Preposition additional materials
- Preposition additional troops at sea
- Develop additional sealift capacity
- Develop additional airlift capacity
- Arrange for increased host-nation support.

No affordable combination of such measures could satisfy any of the four scenarios.

Acceding to the fiscal pressures, the study, with the concurrence of the Steering Committee, then examined three budget-constrained options for enhancing the capabilities of the baseline force to achieve a compromise goal (based on budget realities) of 66 million ton-miles per day for the nation's airlift capacity.

In aiming at a 1986 force posture, the study's final recommendation called for a program that would provide the following:

- 130,000 tons of prepositioned munitions and resupply in Southwest Asia
- Maritime prepositioning of a third brigade-size Marine task force
- 20 million ton-miles per day of additional outsize/oversize airlift capability
- Provisions of adequate support to the Army's D-Day force in Europe through some combination of prepositioning, host-nation support, or other mobility means to be developed after further negotiations with European allies.

The study's recommendations did not directly address bulk cargo, except to assume that some combination of host-nation support and mobility means would support forces placed in Europe.

RAND's Southwest Asia Mobility Study of 1984 Focused on Moving Units. For a deployment from Charleston to Dhahran, RAND estimated that it would take 11 days to deploy the 58,000 tons of materials that are needed by one airborne division and its associated combat support units,[15] given the following assumptions:

- What evolved as the actual 1990 military airlift force, including the 50 C-5 aircraft procured since 1984
- Allocation of 80 percent of the C-5 and C-141 aircraft assigned to operational units (PAA) for purposes of supporting the deployment

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[15]Under the same assumptions, it was estimated that the 12,200 tons for just the airborne division, absent its support materials, would take 4.8 days to deploy, if all airlift resources were dedicated to the division. See Dadant et al. (1984).

- Aerial refueling of all C-5 and C-141 aircraft, rather than making en route stops
- Utilization rates of 12.5 hours per day for the C-5 and the C-141
- 37 CRAF 747-equivalent cargo transports.

A heavy division, along with its support materiel, was shown to require the full attention of all airlift assets for almost three weeks.

Even with what have subsequently proved to be optimistic assumptions, deployment of a full division to Saudi Arabia was projected to require a maximum airlift effort from almost two to as many as three weeks, depending upon the type of division.

Sustainment and bulk cargo were not directly addressed in a manner that would have allowed consideration of procuring civil-style transports to supplement the military-style transports.

DoD's Mobility Requirements Study of 1992 Also Had a Traditional Event Focus

The nation's most recent assessment of its overall requirement for emergency mobilization is defined in the Executive Summary of the Mobility Requirements Study that was conducted for and approved by the Joint Chiefs of Staff.[16] Initial results from this study were reported to yield requirements in excess of what some believe to be affordable levels in the context of current fiscal pressures. This forced the Joint Staff to accept a risk-management approach to produce an affordable set of mobility requirements.

The Mobility Requirements Study assumed that the capability to handle the Middle East or Persian Gulf scenario with moderate risk will be adequate for any other major regional contingency. It identifies the total mobility requirement as the prepositioning, sealift, and airlift assets linked to a transportation system in the United States to deploy the following forces:

- Early Risk Period (first 2 weeks):
  - Marine Expeditionary Brigades
  - Army light forces
  - Navy carrier battle groups
  - Army heavy brigade
  - Air Force combat squadrons
  - Special operations forces
  - Combat support and combat service support

[16]Joint Chiefs of Staff (1992).

- Late Risk Period (3rd to 8th weeks):
  - Army heavy divisions
  - Additional special operations forces
  - Marine Expeditionary forces
  - Theater support forces
  - Additional Navy carrier battle groups
  - Additional Air Force combat squadrons.

This requirement calls for early delivery (first two weeks) of a mix of heavy and light units. A reasonable division of effort would have sealift deliver the heavy units and the Marine's equipment from prepositioned materiel afloat. Airlift would then concentrate on moving the Army's light units and the Air Force's combat squadrons. For airlift, such a scenario closely matches the early phase of the Gulf War airlift. The need for outsize airlift capacity would be quite low, probably in the neighborhood of 10 percent of the cargo moved by air (see Figure 2.5 for the Gulf War experience).

But the New World Lacks Compelling Evidence for the Right Planning Event

Under the new world conditions, absent a Soviet Union, threat-driven analyses are harder to perform and harder still to use as a basis for justifying substantial allocations of resources for airlift capabilities that take a decade to acquire and then will be in service for 25 or more years.

The opportunity for an Iraqi-like force to emerge on the world scene and to threaten U.S. and allied interests remains quite real and indeed likely given the past 100 years of world history. What is different is that the lethality of weapons has gotten nastier, and the speed of combat has become far more rapid.

Indeed, even in a rematch of the Gulf War it is unlikely that the adversary would again allow six months for the United States and its allies to mass such a substantial air and ground force given that the initially deployed units seemed so vulnerable to an Iraqi attack during the early days and weeks of Desert Shield. The bottom line is that rapid airlift is becoming more important as the lethality of available weapons expands and as the length of conflicts becomes shorter. These considerations seem more important than trying to predict the precise circumstances within which airlift will be applied.

Thus, it seems reasonable to assume that dealing effectively with the new world conditions probably means less about predicting specific threats and more about having sufficient capabilities to handle a broad range of situations on a truly global basis, as suggested by the Air Force's emphasis on Global Reach, Global Power.

We Need to Keep an Eye on Basic Principles

Because event-oriented planning may be too limited, planning should also reflect consideration of basic mobility principles that have been articulated in National Security Strategy documents:

- We must be able to deploy substantial forces and sustain them in parts of the world where pre-positioning of equipment will not always be feasible, where adequate bases may not be available . . .
- Our strategy demands we be able to move men and material to the scene of a crisis at a pace and in numbers sufficient to field an overwhelming force.
- The success of our forces in the war to liberate Kuwait was stunning, but we should not allow it to obscure the fact that we required 6 months to deploy these forces . . .
- And, over the longer term, we must challenge our technology to develop forces that are lethal but more readily deployable and more easily sustained than today's.

With respect to these basic principles, we explored a hypothetical example of a situation that might suddenly reverse what we have assessed to be the current trends in the demands for airlift.

A Potential Trend Buster: Prompt Forced Entry by a Major Fighting Force

Although the threat of a massive nuclear exchange has lessened immensely, a proliferation of nuclear weapons and means for delivery may increase the number of potential adversaries capable of using nuclear weapons to threaten the United States and its national interest. Thus, although the threat of massive conventional warfare in Europe has declined, the threat of so-called lesser scenarios boiling over into a nuclear confrontation may be increasing.

We considered a strategy that would be aimed at making prompt global insertion of a major fighting force a primary objective. Although only a rare emergency might require rapid assault landings by major waves of fighting forces to secure sea and aerial ports for follow-on forces, an affordable airlift force built around such a capability would provide the greatest degree of military flexibility for providing prompt global reach and control of emergency situations.

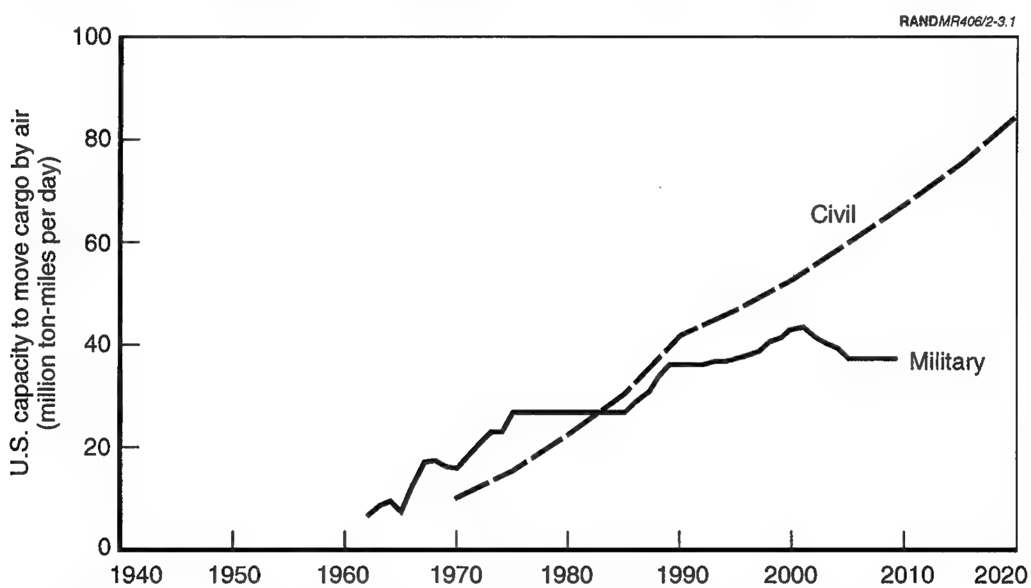
Such a scenario is a substantial departure from the classical intertheater mobility scenario. Ground forces would have to load transports at many airfields simultaneously. Transports would have to be refueled during flight. At the destination, we would need maximum use of air drop, low-altitude parachute extraction, and engine-running combat offload of transports. In one of our early scenarios, several hundred tankers were required to support the first night's operations.

A deployment that emphasizes early landing of large amounts of combat equipment in a moderate threat environment requires a mix of airlift resources that is very different from a situation that allows a couple of weeks for sealift and airlift to deploy equipment and supplies in advance of the commencement of combat operations. In estimating the right mix of military and civil airlift resources, we remained mindful of the need to assure a core capability to respond to such a situation.

Chapter Three

THE SUPPLY OF CIVIL AIRLIFT HAS SERIOUS LIMITATIONS

Notwithstanding significant projected growth in civil-air–cargo capacity for the future (Figure 3.1), the Gulf War airlift confirmed previous indications of serious limitations on the dependable supply of civil airlift for major emergencies. Understanding and addressing the limitations of CRAF are important, because CRAF is a very cost-effective way to maintain a reserve airlift capacity. Consequently, the government has a large stake in improving CRAF where that is possible. However, because improving CRAF will be difficult, it is also important to understand the limitations of even an improved CRAF to shape the military airlift fleet to best complement CRAF's real capabilities. See Figure 3.2 for a guide to this chapter.



SOURCES: Low–growth-rate projection by the International Air Transport Association; Military Airlift Command, November 1991.

Figure 3.1—Expect Continuing Growth in Civil-Sector Capacity to Move Cargo by Air

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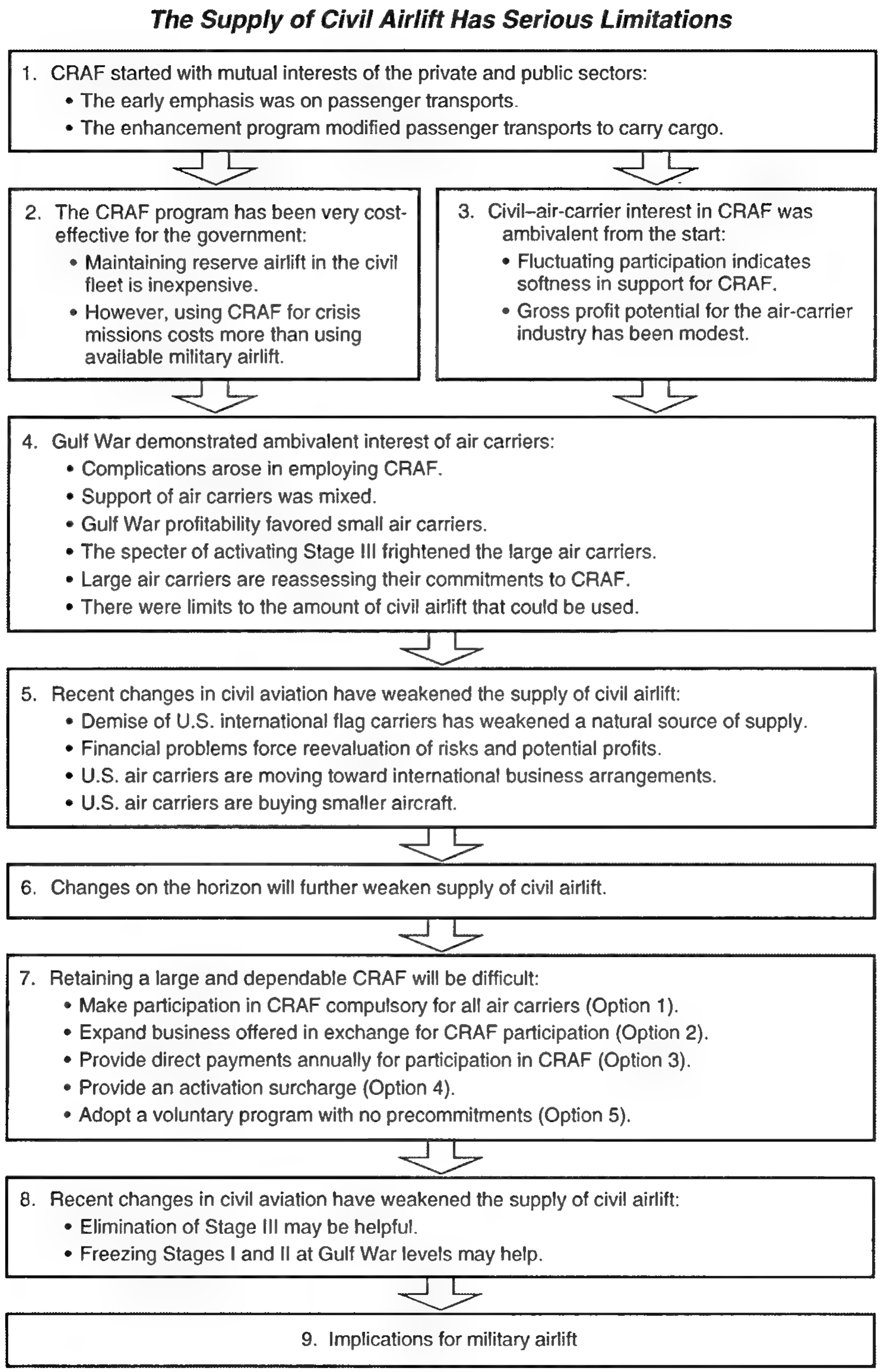

Figure 3.2—Flowchart for Chapter Three

CRAF STARTED WITH MUTUAL INTERESTS OF THE PRIVATE AND PUBLIC SECTORS

CRAF grew out of the mutual interests of the private and public sectors, and for 40 years it has provided a vehicle for managing civil augmentation of military airlift. CRAF evolved in two principal steps: The basic program started in the early 1950s, and the CRAF enhancement program was added in the 1970s.

The Early Emphasis Was on Passenger Transports

During the late 1940s and early 1950s, the civil air carriers, struggling to build new international markets, were anxious to secure the DoD's international passenger business to help remedy their weak financial condition. The carriers, therefore, lobbied the Congress to prohibit the Air Force from using its military transports to carry armed services personnel over fixed international routes. They argued that if they were to be expected to develop and maintain meaningful international airlift capabilities that could help supply airlift for the nation's emergencies, such as they had for the Berlin airlift, then it was unreasonable to force them to compete with the Air Force's government-subsidized operations.

Due to the major shortfall in airlift capabilities for the European scenario and limits on the resources that could be allocated for military transports, the Air Force made strong efforts to enlist air carriers and their long-range transports for the long-range segment of CRAF. To encourage maximum air-carrier participation in CRAF, it was in the government's interest for the Air Force to allocate peacetime business to individual air carriers in accordance with the type and amount of airlift capability each carrier commits to CRAF. By 1959, the Air Force was using CRAF carriers for 39 percent of the passengers it was responsible for moving for the armed services (Figure 2.3). Seven years later, it had climbed to 90 percent, a level it has since remained near. By the mid 1970s, the CRAF carriers were moving about 10 percent of the cargo that the Air Force was moving over the channel routes. This amount has climbed in recent years to about 25 percent.

The Enhancement Program Modified Passenger Transports to Carry Cargo

During the 1960s, the Air Force successfully enlisted a large commitment of passenger transports from civil air carriers. Following Pan Am's introduction of the 747, the civil-aviation industry followed suit with widespread incorporation of the long-range wide-body aircraft (747, DC-10, and L1011) that were designed during the late 1960s and early 1970s. This occurred simultaneously with the prodigious growth of the passenger segment of the civil-aviation industry. This soon created a situation where the shortfall in airlift for the European scenario was far greater for cargo than for passengers. Passenger transports can only carry passengers on their main decks because their doors are small and their floors are too weak for cargo. So, the United States could achieve a more balanced national airlift capability if air carriers could be persuaded to modify some of their wide-body passenger transports so that they could be configured during a major airlift emergency to carry cargo.

The original goal for the program was to modify 100 747s. Pan Am volunteered 19 of its 747 aircraft, which were modified by adding a large cargo door and a floor that was strengthened to carry pallets of cargo. Other U.S. carriers modified four aircraft for this program. In total, funds were only provided to modify 23 aircraft.

Initially, carriers could only commit aircraft to the enhancement program that would remain in passenger service. Later the program was modified to allow a carrier to use such a modified aircraft for moving cargo on its main deck. Such a carrier, however, had to pay half of the costs of the modification. Carriers who abide by the original prohibition are eligible for

- full reimbursement of all costs associated with the modification
- compensation to pay for the added fuel that the modified aircraft would consume during the term of the program.[1]

THE CRAF PROGRAM HAS BEEN VERY COST-EFFECTIVE FOR THE GOVERNMENT

Because maintaining reserve airlift in CRAF is much less costly than maintaining reserve capacity in the military airlift fleet, the CRAF program has been very cost-effective for providing the civil sector's types of airlift capabilities.

Maintaining Reserve Airlift in the Civil Fleet Is Inexpensive

To assess the long-term cost and effectiveness of the CRAF concept, we estimated the reserve capability maintained by CRAF and that maintained by the military airlift fleet (Figure 3.3). We then estimated the 30-year life-cycle cost to the government of acquiring and maintaining those two capabilities (Figure 3.4).[2] Figure 3.5 shows the average annual total cost per unit of reserve capability for this 30-year period. For purposes of this illustration, we assumed that the reserve capacity depicted in Figure 3.3 is reasonably representative of this 30-year period.[3] A similar illustration could be constructed for the passenger segment of CRAF.

Reserve Capacity over 30 Years Has Been Substantial. In illustrating the reserve capacity for emergencies, Figure 3.3 also illustrates a fundamental difference between how the civil and military sectors produce that capacity. Note that a Stage III activation of CRAF would divert about half of the capacity in daily use from the civil sector. Stage II, on the other hand, entails less than one-third the amount of a Stage III acti-

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[1]The addition of the cargo door increased the weight of the aircraft's structure, as did the replacement of the passenger floor with a strengthened floor for cargo. These modifications made the aircraft heavier and increased fuel consumption. The Air Force calculated the cost for the additional fuel that would be consumed over the length of the program and compensated the air carrier accordingly. Being short on cash at the time, this advance payment was very attractive to Pan Am.

[2]For this analysis we selected the period 1961–1990, because 1990 was the latest year for which information was available.

[3]This assumption appears to overestimate the 30-year average capacity by about 25 percent for both CRAF and military airlift.

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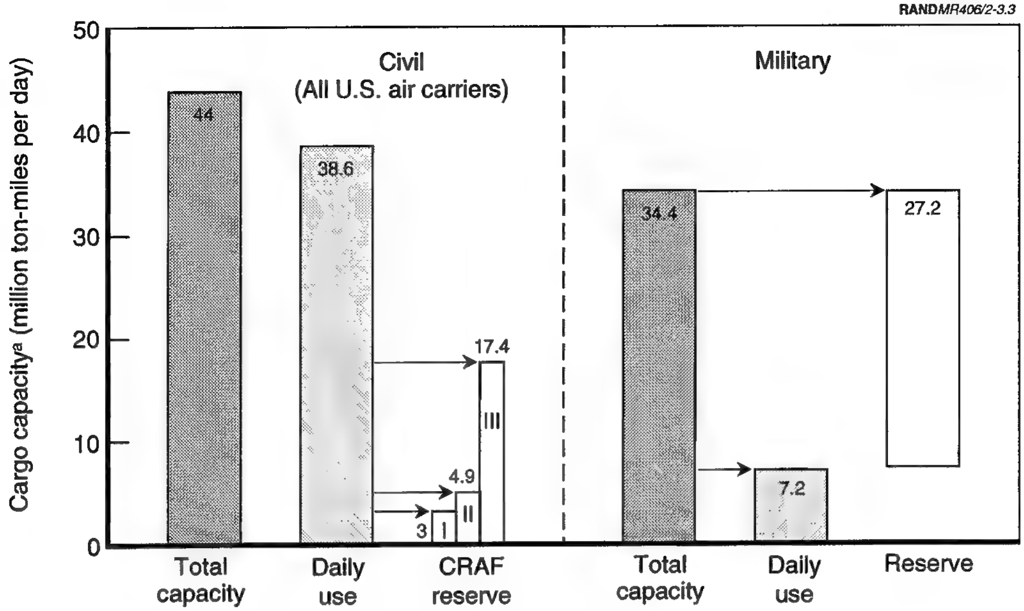

[a]Long-range aircraft only (excludes 737, C-130, etc.).

Figure 3.3—Reserve Capacity for Emergencies During 1989

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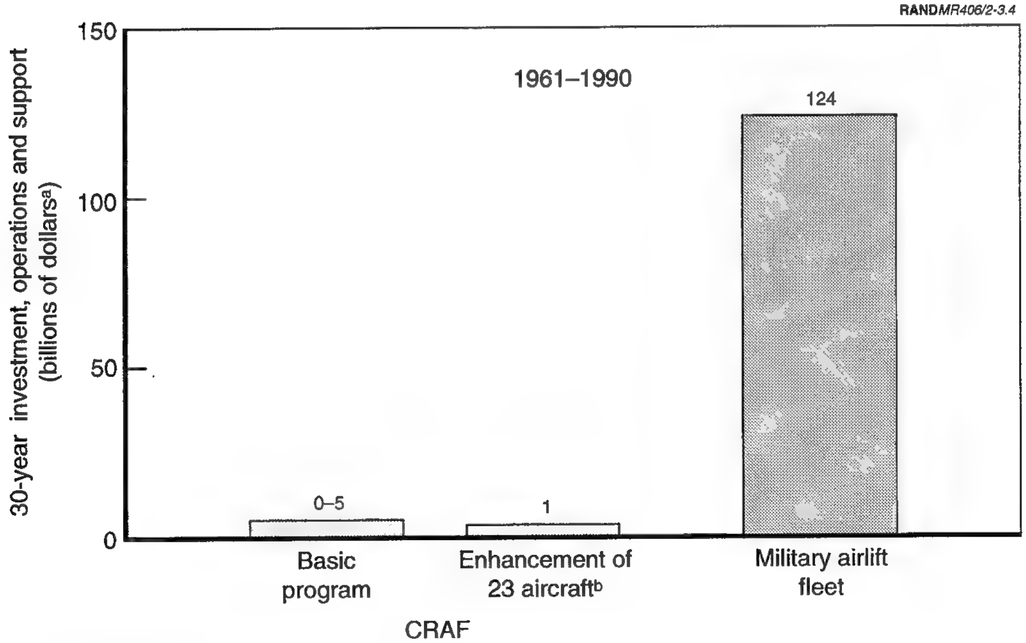

[a]1991 dollars.
[b]Floors of passenger transports upgraded to normal cargo capability.

Figure 3.4—Cost of Reserve Capability, 1961 Through 1990

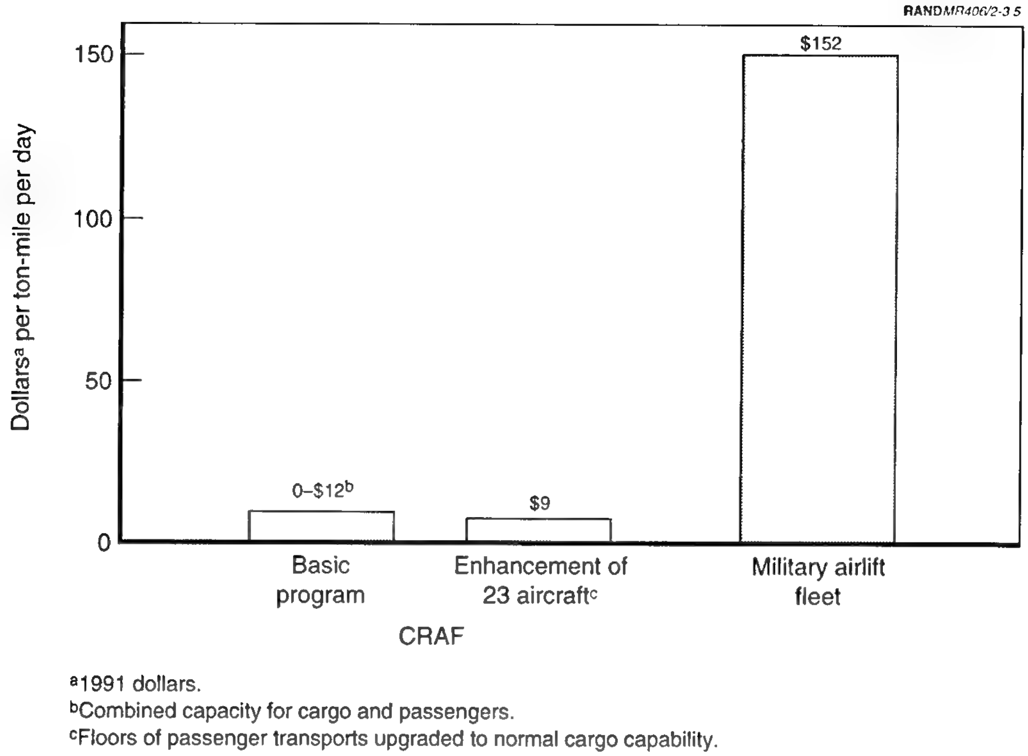

Figure 3.5—Average Annual Total Cost per Unit of Reserve Capability, 1961–1990

vation. The dramatic increase from Stage II to Stage III was at the heart of the resistance by the civil sector to a Stage III activation in January 1991. Reserve capacity in the military sector is fundamentally different in that, by definition, the reserve is that portion that is not in routine daily use. To have adequate capacity for major crises, the military airlift fleet has a total theoretical capacity that is about five times the average daily use. While it is true that from time to time airlift requirements will dip into that reserve, the reserve indicated in Figure 3.3 went mostly unused during the 30-year period of interest.

Cost of Building Reserve Airlift in CRAF Is Low. Figure 3.4 presents the estimated cost of the CRAF program over the 30-year period, as well as the estimated cost of maintaining the reserve capacity identified in Figure 3.3. The basic CRAF program has cost the government between $0 and $5 billion over the 30-year period. Given the relatively low rates that the government has paid the civil air carriers (discussed later) for the air services that have been provided under the provisions of the CRAF arrangement, the basic CRAF program may have cost the government virtually nothing.[4] On the other hand, one can make the argument that the military transports might have carried the loads allocated to the CRAF carriers at a lower marginal

[4]The government, of course, paid for the airlift services rendered (for moving passengers and cargo), but it did not seem to pay a premium for the right to activate CRAF. It appears that right was obtained as a "no-cost" condition of doing business with the government.

cost. For example, training missions with partially loaded aircraft might have carried fuller loads. Given such a point of view and assumptions supporting it,[5] we constructed a cost estimate of as much as $5 billion as the opportunity cost for giving business to the CRAF carriers over this 30-year period.

The CRAF enhancement program accounted for about 3.6 million ton-miles per day of capacity. By the time of the Gulf War airlift, however, most of the Pan Am 747s had been taken over by the companies who were leasing the airplanes to Pan Am. These companies had no responsibility to fulfill the commitments that Pan Am had made to the government.[6] Furthermore, the CRAF enhancement aircraft were in Stage III of CRAF, so the government's agreement with Pan Am did not apply, because Stage II was the highest level of activation. Consequently, the CRAF-enhanced aircraft contributed few missions to the overall Gulf War airlift effort. Even so, the combined heights of the first two bars in Figure 3.4 are quite small compared to the cost of maintaining the reserve capability in the military sector.

Cost of Building Reserve Airlift in the Military Fleet Is High. For the 30-year period, 1961–1990, we estimated the expenses for military airlift (1991 dollars), as shown in Table 3.1. These expenses were partially offset through an estimated reimbursement for services amounting to $49 billion. The unreimbursed expense of $124 billion is presumed to be attributable to the reserve capability maintained over the 30-year period.[7]

Cost-Effectiveness Comparison Shows CRAF's Value. Figure 3.5 presents a cost-effectiveness measure that was derived by taking the ratio of the results in Figures 3.3 and 3.4. The annual cost in dollars per ton-mile per day of capacity of the CRAF

Table 3.1

Estimated Expenses for Military Airlift, 1961–1990

Cost Category	Billions of Dollars
Aircraft procurement and major modification	40
Personnel	78
Fuel	22
Maintenance, supplies, and equipment	15
Transportation, facilities, and services	18
Total	173

[5]The assumption is that military transports could have carried the same loads for 25 percent less cost because there already was a certain amount of flight activity on the routes of interest by military transports. This assumption is based upon a rough judgment about the number of additional flights the Air Force would have had to add and the marginal costs of those flights. We did not try to refine this assumption, because such refinement would not have a significant effect on the final result. For example, even if the Air Force could have provided the same services for 75 percent less cost, that additional savings still would not come close to being sufficient to purchase the additional reserve capacity provided by the CRAF.

[6]The government had paid Pan Am in advance for the cost of additional fuel that would be consumed but had not attached any rights to the aircraft beyond Pan Am's commitment to the CRAF program.

[7]The estimate in effect includes prorated shares of costs for production, operations, and support from each of 30 years commencing with 1960. RDT&E costs were excluded based upon the thinking that we are only interested in understanding the "extra" costs associated with the "extra" (reserve) capacity.

program is somewhere between \$0 and \$12 for the basic program, and \$9 for the enhancement program. In contrast, the annual cost per ton-mile per day of capacity in the military sector is \$152.[8] Figure 3.5 illustrates the overwhelming cost-effectiveness of the CRAF program for the government. Fees to the CRAF carriers either during activation or even over the 30-year period depicted in Figure 3.5 could have been quite substantial and still the government would have enjoyed a cost-benefit advantage. Thus, the government has considerable opportunity to increase the incentives for participation by the CRAF carriers and still have a highly cost-effective program compared to maintaining reserve capacity in the military sector. Of course, the presumption here is that capacity maintained in the civil sector would have military utility. For what we assess to be a very small cost, the DoD has had on call a very substantial amount of civil-style airlift capacity. Replacing this capacity with military airlift would have cost about \$3 billion annually.

A Mix of Military and Civil-Style Airlift Minimizes Costs. Because the cost of reserve capacity is so much greater in the military airlift sector than the civil airlift sector, the total cost of the nation's airlift capability is significantly influenced by the mix of military and civil resources. As we will see, the irony is that, to the extent DoD depends more on the civil sector, the willingness and ability of the civil sector to play such a role may diminish under the arrangements that have thus far governed the CRAF program.

However, Using CRAF for Crisis Missions Costs More Than Using Available Military Airlift

Although building reserve capacity in CRAF is far more cost-effective than building the reserve in the military airlift fleet, the reverse situation pertains when the subject becomes one of the budget costs incurred when the reserve capacity is actually used. Drawing on the budget costs from the deployment phase of the Gulf War airlift, Figure 3.6 shows that it is less costly to use all available military transports than it is to hire civil transports to support a deployment, such as that for the Gulf War. The difference here is that the government has already paid for the military transports and their crews.

Because the Air Force did not immediately use all of its airlift capacity before activating CRAF Stage I, there is an interesting cost question regarding the relative marginal costs of using civil transports versus available military airlift capacity. Even after adjusting for the costs of activated personnel, our calculations indicate a much higher marginal cost for using civil transports than for using military transports. Thus, from a financial vantage point, it costs less to apply all available military airlift resources before calling upon CRAF carriers.

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[8]\$124,000 million/(27.2×30) = \$152 million annually per ton-mile per day of capacity.

\$5,000 million/$[(17.4 - 3.6) \times 30] = 12$.

\$1,000 million/$(3.6 \times 30) = 9$.

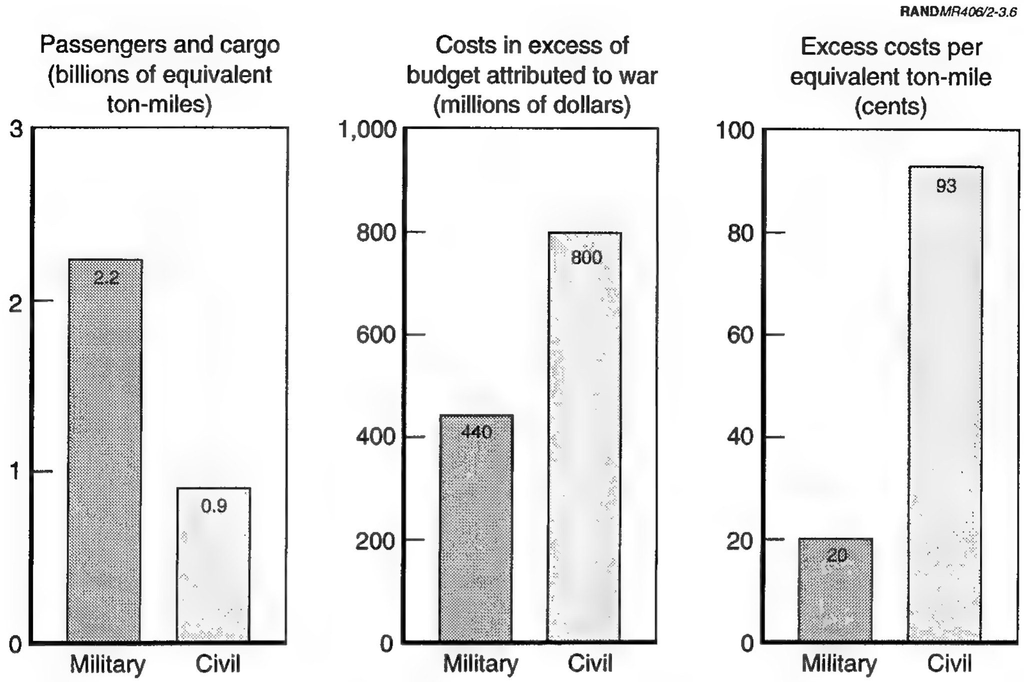

Figure 3.6—Airlift Marginal Cost Based upon the Deployment Phase of the Gulf War Airlift

Notwithstanding the cost difference, however, other factors may shift the preference to civil transports when moving troops because of the very large passenger loads that a single wide-body aircraft can carry. Fewer air traffic control slots would be required. Less space would be consumed at military airfields en route, because the civil transports use civil fields for such stops. Finally, less ramp space may be required at the destination per passenger delivered as well. Thus, even though using available military airlift is less costly than calling upon CRAF, there may be overriding operational considerations for using civil-style transports.

The reasons for maintaining a significant CRAF capability, therefore, include both considerations of the relative expense of building reserve airlift as well as the effectiveness of civil-style transports in providing their types of capabilities.

CIVIL–AIR-CARRIER INTEREST IN CRAF WAS AMBIVALENT FROM THE START

Although the air-carrier industry wanted the government business, the CRAF commitments by the industry have shown signs of softness through the history of the program. This seems to reflect the modest opportunities that the industry has had to profit from the business it receives in exchange for its CRAF commitments.

Fluctuating Participation Indicates Softness in Support for CRAF

Commitments of the air carriers have fluctuated throughout the history of the CRAF program, as illustrated in Figures 3.7, 3.8, and 3.9. Delta, mostly a domestic carrier at the time, had little interest in the CRAF program (Figure 3.7), even though it operated a number of wide-body L1011 transports of the type that contributed to the Gulf War. Eastern, although offering transports for the short-range segment of CRAF (not addressed by this research), did not participate in the long-range segment after the mid-1970s. The three predominately international carriers during this 30-year period have accounted for the bulk of the airline commitment to CRAF. Of concern is the fact that each has encountered financial difficulties that have resulted in either curtailment of operations or pursuit of financial arrangements with a foreign carrier.[9]

Figure 3.8, similar to the last, shows CRAF participation for major cargo carriers. In addition to the fluctuation in commitments, another important point relative to dependability is the exiting of carriers (denoted by the dashes) from the business. Recently, Emery/Rosenbaum has also exited.

Figure 3.9 shows a summary of how the support of the air carriers for the long-range international segment of the CRAF program has fluctuated over the past 30 years. If CRAF were uniformly profitable for all carriers, we would expect steady support for

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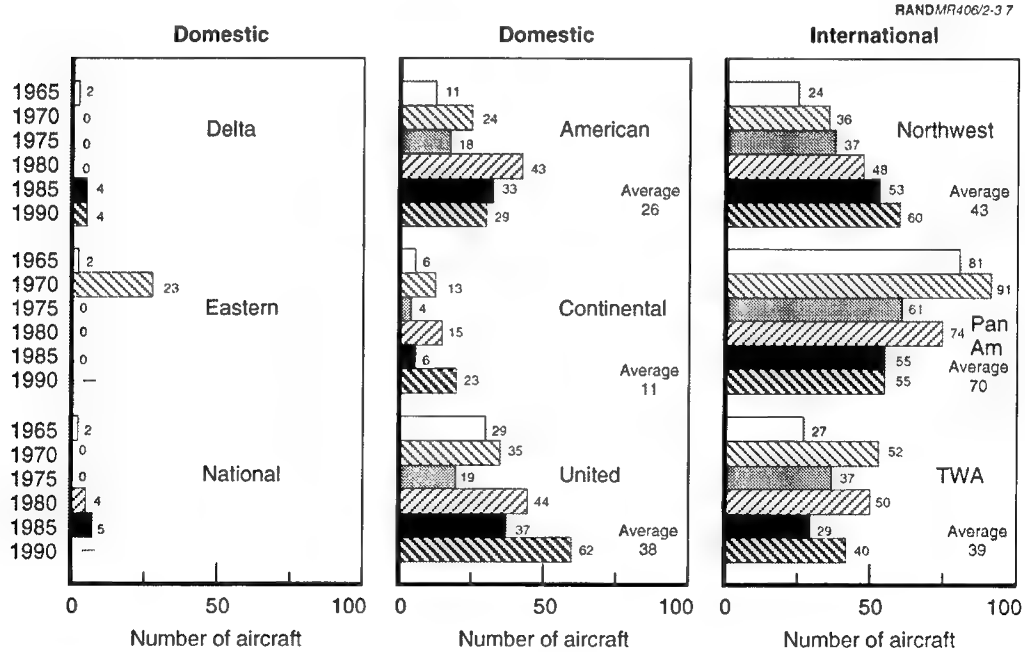

Figure 3.7—Passenger Aircraft Committed to CRAF Stage III by Major Airlines, 1965–1990

[9]The main reasons for their difficulties could not be the CRAF program, because it accounts for such a small portion of their business.

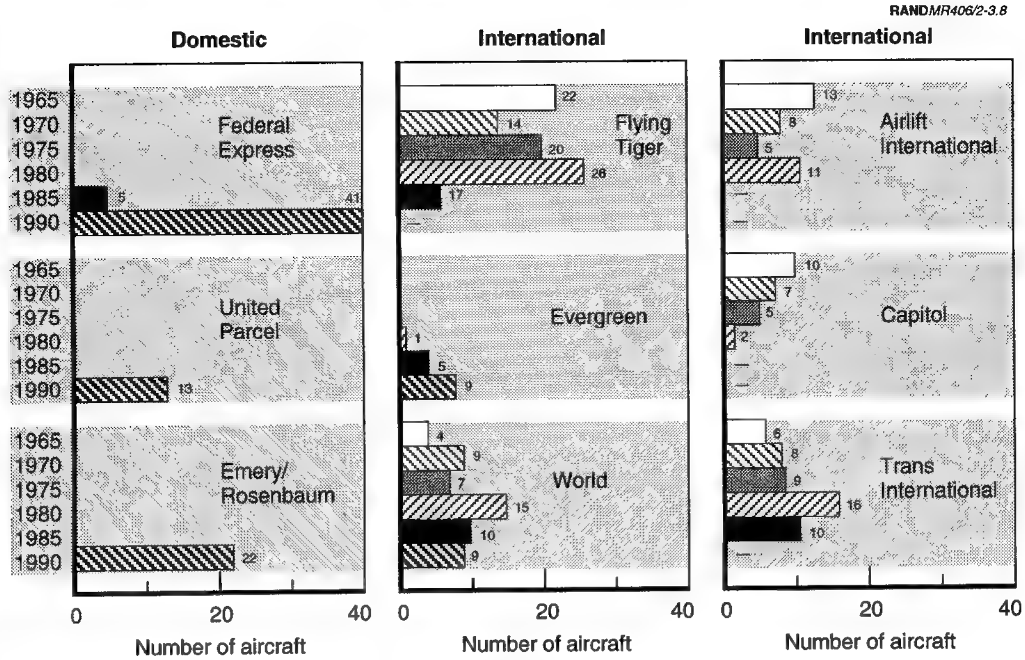

Figure 3.8—Cargo Aircraft Committed to CRAF Stage III by Major Cargo Carriers, 1965–1990

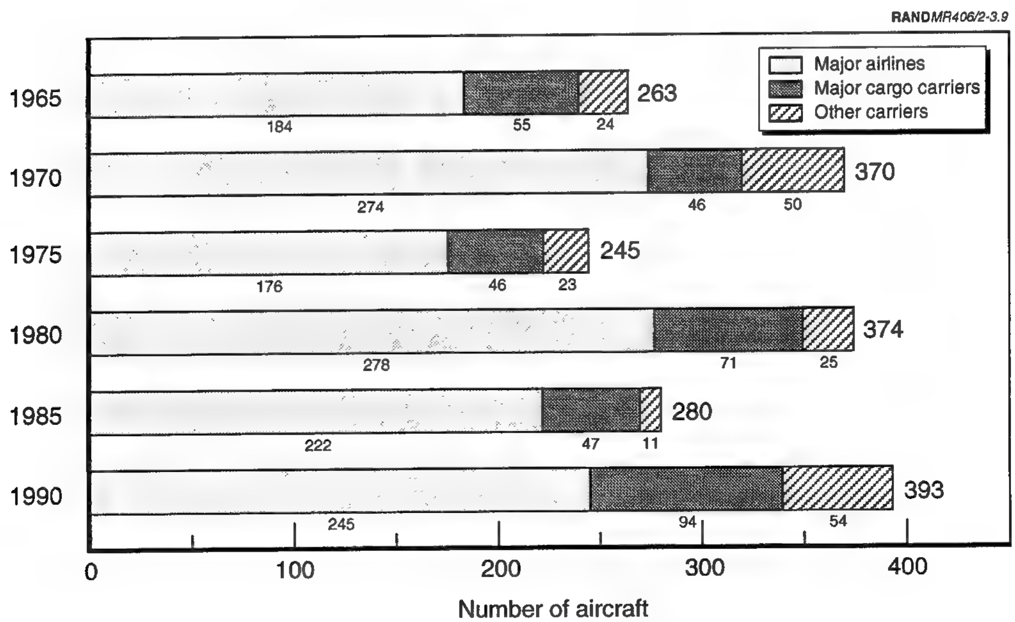

Figure 3.9—Inconsistent Commitment to CRAF Stage III, 1965–1990

the program. Fluctuating support suggests that some carriers have had less than full enthusiasm for the program, presumably because they did not see sufficient opportunity for profit. Some may have participated more for patriotic reasons (and assuming that a major conventional war in Europe was unlikely) than because it made good business sense.

Another very important point from Figure 3.9 is the fact that the major carriers have accounted for over 85 percent of the aircraft committed to CRAF Stage III. In contrast, a majority of the Stage I and II aircraft come from the small air carriers.

Gross Profit Potential for the Air-Carrier Industry Has Been Modest

Clues about how air carriers viewed the profitability of CRAF are evident in inconsistent commitment by civil aviation, incomplete commitment by individual air carriers, and variations in air-carrier commitments over time. If the CRAF program was profitable for all air carriers, we would expect every carrier to commit all eligible aircraft to the CRAF program until either airlift needs were satisfied or all eligible aircraft had been committed. This, however, did not happen. A shortfall remained in airlift capability (Figure 1.4), and the air carriers had eligible aircraft that they did not commit. To assess the extent of the potential profit for air carriers during the 1960–1990 period, we examined potential revenue generation per seat-mile and gross potential for profit.

Potential Revenue Generation per Seat-Mile Favors Charter Operators. Examination of selected city pairs (Figure 3.10) suggests that the CRAF air carriers have been providing services to the Air Force at rates that are lower than Government Services Administration (GSA) rates and only half of the industry's average revenue per seat.

Figure 3.10 compares user ticket costs with the amount that the Air Force's MAC (now the AMC) paid the CRAF air carriers for various city pairs. Users buying tickets from the air carriers paid an average price estimated by the top bar. The estimate is based upon worldwide average yields per revenue seat-mile. As an average, it includes the full range of prices from the deepest discounts through full coach fare (also indicated in the chart) to first class. The GSA ticket price is the actual rate for the indicated city pair. The MAC ticket price is also the actual rate for the city pair.

The MAC payment to the air carrier was calculated using the uniform rate offered by the Air Force in the Request for Proposal for the next three-year CRAF contract. This rate was applied both to charters (about three-fourths of the CRAF passenger business) and to Category Y blocks of seats (at least 20 seats per block). Since it is a charter rate, the bar would have a length more like the average price bar if it were adjusted for load-factor effects. Few of the major carriers, however, are even involved in charter operations, much less possess a well-run charter operation. For many of the large carriers, therefore, the view of the profit opportunity may not be great.

Profitability also varied across companies because the Air Force sets a uniform rate that reflects average costs rather than individual air-carrier costs. Finally, the Air

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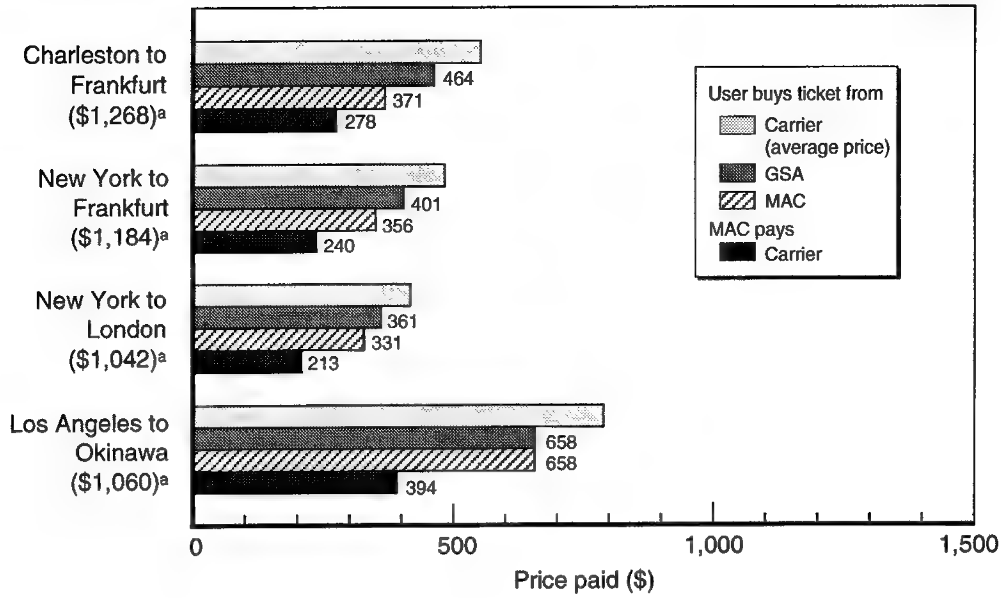

[a]Full coach price, based on 1992 RFP rate: $0.0675/seat-mile.

Figure 3.10—Comparison of Ticket Costs Paid by Users and Payments to CRAF Carriers

Force has set the rate structure based upon average costs for charter operations.[10] Few of the major airlines still maintain charter operations, because small charter operators have been able to maintain lower prices for charter services.

Gross Profit Potential Has Been Modest. Since the Vietnam War, the annual amount of business provided to the CRAF carriers has ranged from a low of $368 million to a high of $592 million. During the 1980s, the average annual amount was $535 million.[11] For the 1970–1989 period, CRAF-related business for the civil air carriers accounted for total revenues of $12.5 billion (1991 dollars). Extrapolating to the 30-year period of interest for this research (1961–1990), we estimate total revenues of $19 billion. If the true profit margin for this business were 1 percent of revenue, the air carriers realized a profit of $190 million. At a 5-percent profit margin, the profit would have been $950 million. Even the most profitable air carrier, however, rarely achieves a 5-percent margin for an extended period of time.[12] Moreover, the long-term average profit margin for the industry has been less than 1 percent. From the vantage point of the industry's experience, which is dominated by the experience of

[10]The rate-making function had been provided by the Civil Aeronautics Board before it was disbanded as part of the deregulation of the airlines.

[11]All amounts are expressed in 1991 dollars.

[12]Although few carriers sustain a 5- to 8-percent profit margin on gross revenues for any long period of time, Air Force personnel responsible for establishing the uniform rates applied to CRAF business report that their calculations show that a well-run charter carrier could generate profits at such levels. They acknowledge that the long-term industry average is less and that some carriers could be as low as the 1 percent we have used for illustrative purposes.

the large air carriers, it seems reasonable to believe that the industry's profit attributable to CRAF participation may not have been more than several hundred million dollars.

This assessment has two potential pitfalls. First, to the extent that government business mostly occupied seats that otherwise would have been empty, the profit margin could be much higher than 5 percent. Second, to the extent that small air carriers have lower costs due to the use of older equipment and due to lower salaries, their profit on the government's business could have exceeded the 5-percent margin. Given the manner in which the government set the fare rates and our discussions with people involved in that process, it seems reasonable to believe that profit margins may have exceeded 5 percent in individual instances, but over the 30 years for all carriers, it is reasonable to assume that the long-term average profit margin was well below 5 percent.[13] This means that the industry's profit potential was at most several hundred million dollars.[14]

GULF WAR AIRLIFT DEMONSTRATED AMBIVALENT INTEREST OF AIR CARRIERS

Although civil aviation made significant contributions in moving troops from their unit APOEs to the Persian Gulf and in moving bulk cargo largely from AMC's channel ports to the Gulf, such support did not come without complications and the mixed support of the air carriers.[15] On the one hand, civil transports had high mission-capable rates and relatively short ground times. Moreover, by using civil airfields for en route stops, they made it easier for the Air Force to move its transports through the military airfields that served as en route stops. On the other hand, a number of difficulties were encountered (see Chenoweth, 1993).

Complications Arose in Employing CRAF

Communications Were Inadequate. Civil transport radios operate on frequencies that are not accessible by the equipment the military uses to communicate with its transports. Thus, civil transports would arrive at military installations without advanced notification to the personnel who would handle servicing, loading, or unloading. Also, when the air war started, civil transports had difficulty assessing the potential hazards at their destination in the theater because of the communication limitations.

Protective Equipment for Chemical Warfare Was Lacking. During the early days of conflict, there were difficulties getting protective equipment to civil crews.

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[13]People involved in setting the fare rates expressed the view that a well-run air carrier could make a 9-percent profit on sales.

[14]This assessment assumes an average level of performance by management. One could argue that the potential would be greater if the air carriers were better managed.

[15]Dover Air Force Base was one of the main bases from which bulk cargo was airlifted to the Gulf.

Deliveries Were Interrupted When the Shooting Started. At the outset of the air war, SCUD missile attacks on airfields introduced a new risk that some air carriers declined to take until their concerns about procedures were addressed by the Air Force. These included landing mainly during daylight and arranging for chemical-warfare–protection equipment for flight crews.

Medical Evacuation Aircraft Were Only in Stage III. All of the long-range medical evacuation aircraft (the 767 ER model) were in Stage III, which was not activated.

Insurance Coverage Had Gaps. Insurance paperwork was deemed excessively cumbersome by air carriers, and reports indicate that some missions were flown without benefit of the government's insurance coverage.

Compensation for Unusual Costs Were Delayed. Disputes in this area were still under negotiation for many months after completion of the airlift.

Although the foregoing difficulties are being addressed, a harder-to-address issue is the ambivalent support of the large air carriers.

Support of Air Carriers Was Mixed

As Figure 3.11 shows, the large carriers responded to the airlift differently than the small carriers in the extent to which they volunteered aircraft above their CRAF commitments. The figure shows that the small charter carriers and the small cargo carriers volunteered far more aircraft to support the peak month of airlift activity (January 1991) than did the large cargo and passenger carriers with two notable ex-

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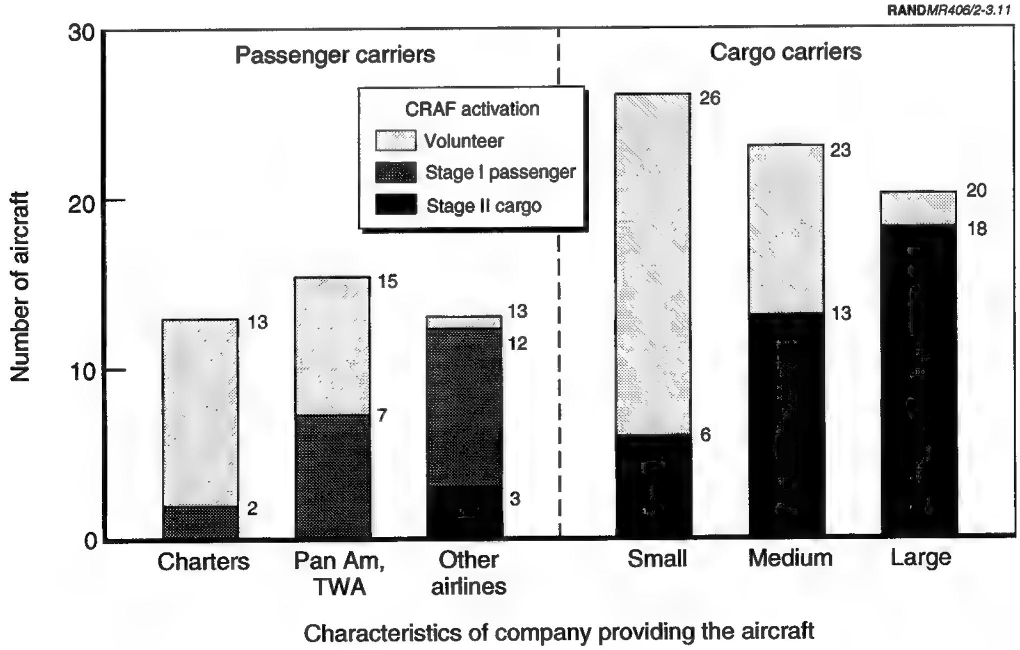

Figure 3.11—Civil Airlift Augmentation of Military Airlift on January 18, 1991

ceptions. At the time of the Gulf War airlift, both Pan Am and TWA had significant excess capacity, were experiencing a decline in demand due to the impact of the Gulf War on their markets, and were either in or near bankruptcy.

The correlation between carrier size and the number of aircraft volunteered above and beyond the requirement is particularly pronounced for the cargo carriers. Because the charter carriers and the small cargo carriers specialize in taking advantage of local opportunities, whereas the large carriers make substantial investments in cultivating market shares in specific markets, the latter group has far more to lose by temporarily exiting a market or cutting back on frequency of service than do the smaller carriers.

The small air carriers were eager for the additional business, but the larger passenger and cargo carriers were more reluctant participants. Figure 3.12 shows a snapshot of the CRAF fleet during one point in the Gulf War airlift. The portion of each carrier's fleet committed to supporting the Gulf War is depicted by the most lightly shaded portion of each bar. Also illustrated is the effect of a Stage III activation of CRAF. Such an activation, if fully exercised, would have been particularly disruptive of the long-range aircraft operations of the major carriers, as well as those of several of the smaller carriers.

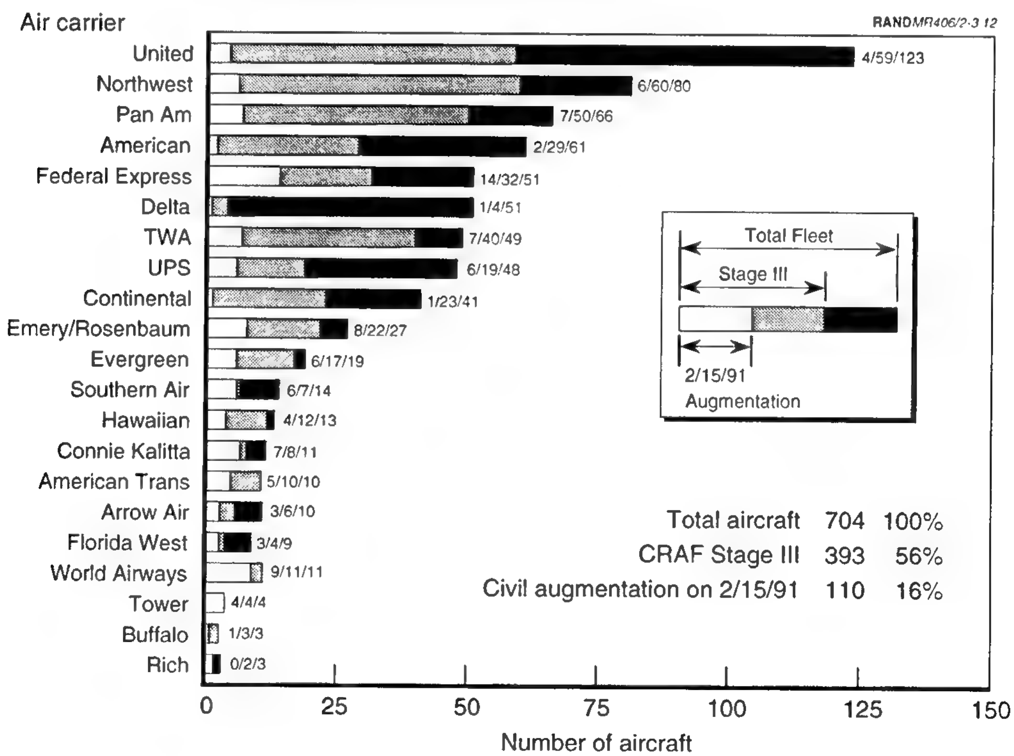

Figure 3.12—Portions of Long-Range–Aircraft Fleets Augmenting Military Airlift on February 15, 1991

The partial commitment of the major air carriers stands in stark contrast to the commitments of the smaller carriers. Note that the major carriers with the greatest percentage commitment were the nation's three major international air carriers: TWA (82 percent), Pan Am (76 percent), and Northwest (75 percent). The deep commitments of these three carriers is a logical consequence of the fact that the government only offers international air transportation business as the incentive for air carriers to commit aircraft to CRAF. The major domestic air carriers were not nearly so deeply committed. The smaller carriers on the other hand are mostly charter operators on international routes. Several, such as World and Evergreen, do business mostly for the government.

Gulf War Profitability Favored Small Air Carriers

To explore the potential profitability of CRAF for the air carriers during the Gulf War, we examined the gross potential for profit and the interest in committing aircraft that varied by sector of the civil-aviation industry.

During the Gulf War airlift,[16] the government purchased $1.7 billion worth of airlift services from the civil air carriers under the provisions of the CRAF program. Gulf War missions accounted for $1.43 billion, and other airlift missions accounted for the remainder. At a 5-percent profit margin, such revenues would yield $72 million in profit. An indication that many air carriers saw CRAF participation in the Gulf War airlift as profitable was the significant number of aircraft volunteered above the CRAF commitments. On the other hand, signs of concern about profitability were the instances where large air carriers offered only that which they were required to provide.

The profitability of involvement in the Gulf War airlift seems to have varied by carrier size and financial condition.

- Small cargo carriers and charters supplied 39 aircraft, five times the number required. They saw a strong opportunity for profit from the Gulf War airlift.
- Major air carriers supplied 30 percent of the civil transports for the Gulf War. Major air carriers, except Pan Am and TWA, supplied required aircraft only, except a single aircraft from Delta, which was volunteered. This suggests that the major air carriers, taking a long-term view, expected a weak opportunity for profit from the Gulf War in view of the prospective long-term damage to market shares.

Moreover, the small carriers, specializing in satisfying spot market demands, were far better postured to arrange for picking up loads in Europe and Asia for the flight back to the United States than were the large air carriers, who mostly serve fixed routes. Whereas the large air carriers mostly flew empty aircraft back to the United States, some of the small air carriers were effective in arranging for loads that were very

[16]Including the return of units to their home locations.

profitable. Because air carriers were paid for missions flown, they were free to use their aircraft, if they could, to carry revenue-generating loads on return flights.

The Specter of Activating Stage III Frightened the Large Air Carriers

Although a majority of the aircraft participating during the peak month from the civil sector came from either the charter carriers or the medium and small cargo carriers, a Stage III activation would have drawn the overwhelming majority of the aircraft from the large carriers. The economic consequences to the U.S. air carriers of a Stage III activation, therefore, are potentially profound; for this reason, the practicality of a Stage III activation is questionable in all but the most dire of circumstances. For example, a Stage III activation would have, if fully exercised, taken 55 of United Airlines' 123 long-range aircraft. In the case of Northwest, it would have taken 54 of their 80 long-range aircraft, and American would have given up 27 of its 61 long-range aircraft. These figures are in addition to the four United aircraft, the six Northwest aircraft, and the two American aircraft that had already been activated.

The two large cargo carriers, Federal Express and UPS, already had 20 aircraft activated by Stage II. A Stage III activation would have increased their commitment to a total of 51 aircraft, leaving 50 long-range aircraft in their fleets. Again, such a heavy commitment to Stage III by the large carriers raises questions about the practicality of calling upon Stage III in all but the most extraordinary of crises.

Large Air Carriers Are Reassessing Their Commitments to CRAF

Now that CRAF has been activated for the first time in its nearly 40-year history, the nation's civil air carriers are reassessing the wisdom of committing approximately 400 of their long-range aircraft to CRAF. During the Gulf War, they saw how activation of just 14 percent of these aircraft caused disruptions to some carriers' abilities to protect their investments in markets where competitors (both U.S. and foreign carriers) did not have the same depth of commitment.

As the Air Force explored the option of a Stage III activation to address the backlog of bulk cargo that had accumulated at Dover Air Force Base, air carriers (knowing of the Air Force's explorations) explored their ability to introduce political pressure to forestall such an activation. Although interviews with people involved on both sides of these explorations produced similar accounts, this remains an area in which very little has been placed on the public record. Similarly, air carrier resistance to a Stage II activation prior to Christmas is another area in which there are signs of difficulty from interviews but little on the public record at this time. We found no reports of serious resistance to the Stage I activation.

Until the Gulf War, few air carriers had expressed serious concerns about the business consequences that might flow from an activation of CRAF. Because consequences are now known, there is no doubt but that the relationship between the Air Force and the air carriers has changed in a fundamental way. Because of the nonuniform commitments to CRAF by competing carriers, some major carriers are rethinking market exposure issues that arise during activation of CRAF. Because a

deeply committed air carrier has a greater proportion of its market share at risk than a carrier with only a token commitment, the deeply committed carrier risks losing a greater portion of its business during an activation. For an airline, as for many other service companies, this is a serious risk. Market shares are hotly contested, and companies make major investments in building up their market shares. The risk for the government lies in deep commitments by a few air carriers that could not realistically deliver on those commitments without incurring substantial damage to their long-term financial positions. Because such carriers can be expected to lobby against activation of the CRAF's larger Stages (II and III), we view such commitments as undependable.

The disadvantages of participating in CRAF may outweigh the benefit that the large air carriers can derive from the DoD's routine international business they receive in exchange for their commitment to the CRAF program. The smaller air carriers seem to have greater flexibility and greater interest in both the routine DoD business and the surges that occur during crises. Although the Gulf War is the only instance where CRAF has been activated during its nearly 40-year existence, large carriers may choose not to participate if they think the likelihood of an activation looms too large. Attempts to shift the civil-military mix heavily to the civil side could therefore undermine the government's ability to enlist civil carriers in the CRAF program that could be depended upon during major crises.

There Were Limits to the Amount of Civil Airlift That Could Be Used

Because the need to airlift bulk cargo during January 1991 so exceeded the capacity of the civil transports, the Air Force assigned additional military transports to help airlift bulk cargo, even though that is not the type of load that they move best. In the instance of this airlift emergency, there were practical limits to the amount of civil airlift that was applied to moving cargo:

- Civil air carriers limited the number of cargo aircraft volunteered.
- The Pentagon decided against recommending activation of Stage III of CRAF.[17]

RECENT CHANGES IN CIVIL AVIATION HAVE WEAKENED THE SUPPLY OF CIVIL AIRLIFT

Demise of U.S. International Flag Carriers Has Weakened a Natural Source of Supply

Of the seven largest U.S. air carriers in 1965, three operated most of the 747 aircraft used by U.S. air carriers. Each accounted for a significant part of CRAF, and all were consistent participants in CRAF. All three encountered significant financial complications. Pan Am went out of business. TWA entered Chapter 11 bankruptcy and di-

[17]Some people familiar with the airlift believe that major air carriers lobbied against the activation of Stage III by the President.

vested itself of some of its international routes. Northwest, to deal with its financial difficulties, entered into a partnership arrangement with KLM.

Of the other four carriers in the top seven in 1965, all were mainly domestic carriers at that time. Their participation in the international airlift portion of CRAF was limited then by their lack of international transports. As their international business grew, however, their participation in CRAF remained limited and/or fluctuated. Eastern went out of business. The remaining three air carriers, American, Delta, and United, are currently the three largest U.S. air carriers. Each now has a significant international operation.

Thus, of the top seven carriers in 1965, three of the financially weakest air carriers in the late 1980s and early 1990s had been the most significant members of CRAF. In retrospect, the combination of overcapacity on international routes and subsidies that foreign carriers received from their governments made the U.S. international carriers very eager for the U.S. government's defense-related air-travel business. That business, however, was never a large part of the carrier's international market. Competition with foreign carriers will certainly continue. The extent to which U.S. carriers remain significant players on the international scene will determine the size of their international airlift fleets.

To explore why some of the key carriers have committed fairly deeply and consistently to the CRAF program, we examined the weak financial condition of the chief U.S. international carriers during the past 30 years. A weak carrier may pursue deeply discounted business to cover immediate costs and maintain cash flow even though it is not recovering enough of its investment cost to refurbish its fleet. An air carrier in such a situation is in a downward spiral and headed for an eventual exit from the business.[18] Thus, participation in CRAF by financially troubled carriers, such as Pan Am, TWA, and more recently Northwest, does not by itself mean that CRAF participation has been profitable for them in the long term.

Financial Problems Force Reevaluation of Risks and Potential Profits

Moreover, the nation's civil aviation industry and its investors are scrutinizing business risks of all types. Record losses during the early 1990s have wiped out the industry's net profits since 1925 and have contributed to the decline of two major supporters of CRAF, Pan Am and TWA. In the context of this fiscal reality, there is an emerging sentiment that the risks posed by CRAF participation are not justified by the levels of business that the government has offered in the past.

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[18]As U.S. air carriers coped with their management problems and competed with foreign carriers' lower labor costs and subsidies, they tended to offer discounts to maintain market share and to generate cash flow. Too much discounted business, however, contributed to losses. Losses added debt and raised costs of servicing debt. Larger loads were then needed to break even. Carriers offered more discounts. Losses increased and carriers ultimately exited the market.

U.S. Air Carriers Are Moving Toward International Business Arrangements

A further concern is the continuing shift toward international ownership of what once were solely U.S.-owned carriers. The arrangements between Northwest and KLM and between U.S. Air and British Airways may signal a trend toward international ownership of the air carriers that the United States is depending upon to augment military airlift capabilities. Moreover, such carriers as Delta are engaging in various types of joint ventures with foreign carriers. Whether conflicts in national interests might arise one day is hard to foretell.

U.S. Air Carriers Are Buying Smaller Aircraft

A final structural change that is affecting CRAF participation is the trend in the composition of U.S. air-carrier fleets away from large transports like the 747 toward midsize transports like the 767 and MD-11 (Figures 3.13 and 3.14). As the composition of U.S. air-carrier fleets is moving away from the 747-size aircraft toward smaller aircraft that offer air carriers greater flexibility in providing frequent service over many routes, most of the large transports are currently being purchased by foreign air carriers. Figures 3.13 and 3.14 illustrate this trend by showing how the purchasers of the 747 have shifted away from U.S. carriers to foreign carriers as the 747 has progressed through its model series from the original -100 model to the most recent -400 model. The only U.S. carriers currently taking delivery of the -400 are United Airlines and Northwest. In contrast, many U.S. carriers took delivery of the -100. Thus, the very large aircraft that are most desirable for CRAF may become harder to enlist because

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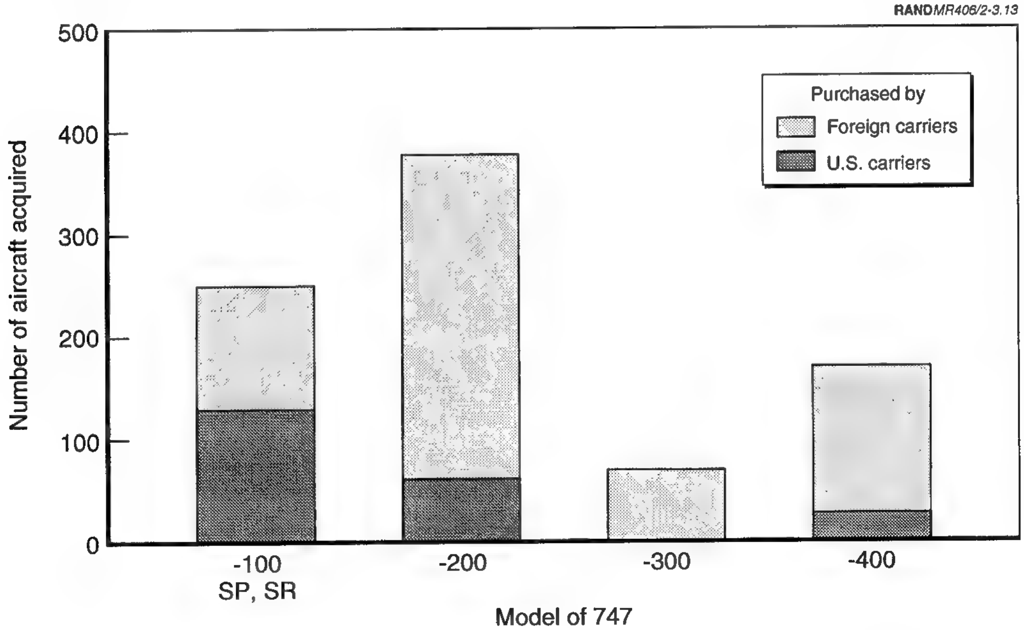

Figure 3.13–Future Role of the 747 in U.S. Carrier Fleets Is Uncertain

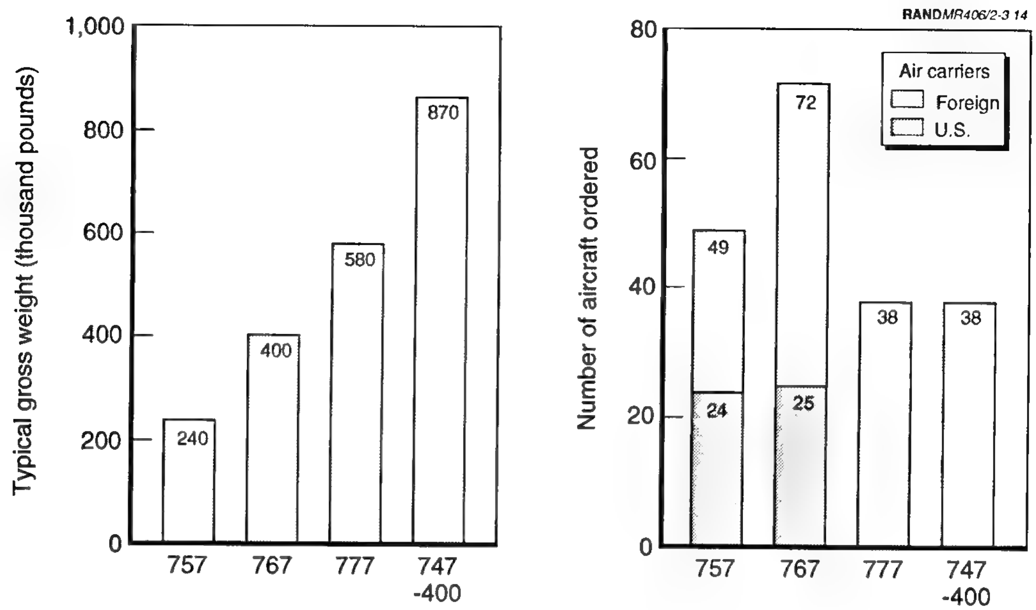

Figure 3.14–Long-Range International Aircraft Ordered from Boeing During 1991

U.S. carriers are shifting to smaller aircraft better suited for their hub-and-spoke systems. Even on the long-range international routes, the U.S. carriers possessing the largest international route systems (American, Delta, and United) lack the volume of business on many individual routes to warrant very large transports. Consequently, for both domestic and international markets, most major U.S. air carriers are shifting the composition of their fleets away from the very large aircraft, which are most attractive for CRAF.[19]

Meanwhile, well-established and in some cases subsidized foreign carriers are capturing larger shares of the international market, which they plan to continue serving with very large transports, such as the 747–400, and Boeing's prospective 600-passenger transport. Regarding a 600-passenger transport, the foreign carriers are pushing especially hard for a whole new airplane with a greater range than that of a full double-deck variation of the 747. As Pan Am was the initial customer that stimulated the launching of the 747—and thereby the era of wide-body aircraft, which are the backbone of the current CRAF—it is now the foreign carriers who are pushing for the next major increase in aircraft capacity. The difference this time is that CRAF may not be an early beneficiary because such an aircraft is not well suited to the current operation of U.S. air carriers.

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[19]The number of 747s operated by U.S. air carriers reached a peaked in 1990 at 195 aircraft. By 1993, the number had fallen to 177. Further decline is expected, because only four have been ordered by U.S. air carriers since 1990. Meanwhile, foreign air carriers operated 581 747s in 1990 and 737 in 1993. Moreover, they have ordered 62 since 1990. Actual deliveries since 1990 are 14 for U.S. carriers and 166 for foreign carriers. Finally, all scheduled deliveries (including options)—through the year 2000—for the 747-400F are for foreign air carriers.

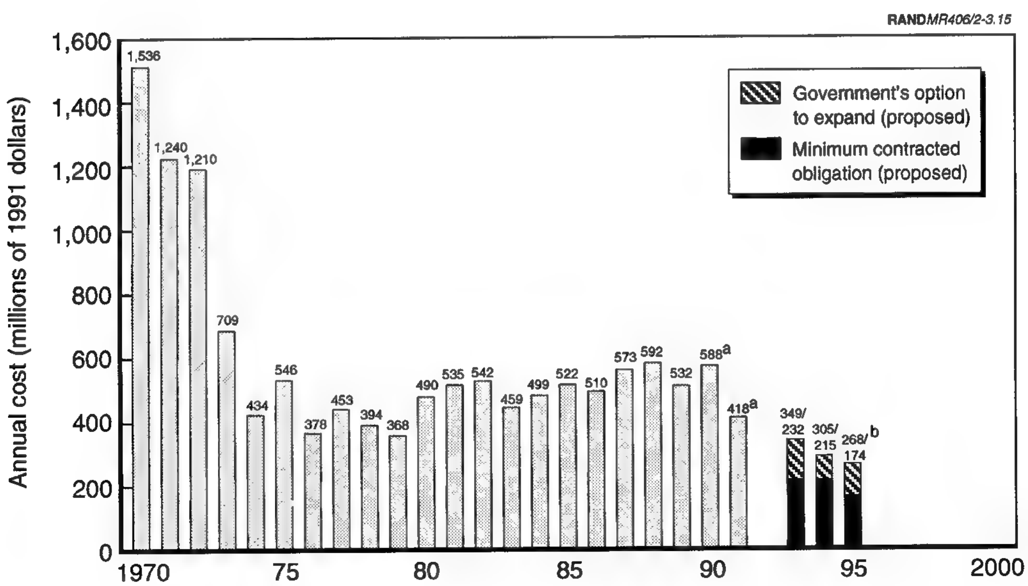
CHANGES ON THE HORIZON WILL FURTHER WEAKEN THE SUPPLY OF CIVIL AIRLIFT

Turning to the future, we compare past levels of business to the 1991 plans for the following three years in Figure 3.15. The drawdown in forces stationed overseas will inevitably reduce the amount of international business to be offered to the CRAF carriers. The declining presence of U.S. military forces overseas threatens to eliminate one-half to three-fourths of the military's routine international airlift needs of the 1980s. The amount of routine business is declining precisely at the time when the air carriers have a much fuller appreciation of the financial and business implications of committing aircraft to CRAF. Moreover, the business offered to the civil air carriers has been mostly passenger, and therefore air-freight carriers have had less opportunity to benefit from the business that is offered in exchange for enlistment in CRAF.

RETAINING A LARGE AND DEPENDABLE CRAF WILL BE DIFFICULT

The long-term viability of something like a CRAF program must be sustained because of the need and the overwhelming cost-effectiveness of the program. Interests in improving the CRAF concept and/or its implementation flow from three concerns:

- Supply of CRAF cargo capacity was insufficient to satisfy demands.
- Large air carriers need better incentives to support CRAF.
- Defense business incentives for CRAF are declining.



aFY 1991 planned program without Gulf War.
b1993–1995 proposed program assuming 1991 projected Base Force.

Figure 3.15—Airlift Services Purchased from CRAF Carriers

To maintain a healthy emergency response capability, the nation needs to explore arrangements with its civil air carriers to ensure the prompt availability of needed types of aircraft in quantities sufficient to secure national objectives in time of sudden crisis. We examined a wide range of possibilities for improving the CRAF concept, its implementation, or both. Some ideas were relatively easy to reject. Others offered more promise. However, upon closer review by RAND and the Air Force, it became apparent that none of the ideas was without potentially serious drawbacks.

Preliminary screening of the possibilities led us to reject the following ideas for the reasons noted:

- **Share ownership of aircraft.** Encourage shared ownership of transports, especially if it would mean a transport type more desirable to the government's interest. Shared ownership raises issues about how to share responsibilities for the condition of equipment and how to share liabilities.
- **Enlist foreign carriers in CRAF.** A further possibility is purchasing airlift services from foreign carriers, especially if the prices that might be charged by U.S. carriers rose too steeply in a voluntary CRAF program (discussed later). This might also provide a way to access the 747s that are increasingly found predominantly in the fleets of foreign air carriers. On the other hand, this approach raises issues of dependability and security.
- **Give civil air carriers access to military airfields.** Although some air carriers could benefit from access to particular airfields, such a benefit would not have value to other air carriers.
- **Use military aircraft to help meet civil-sector surges in demand.** Another possibility would be to increase the size of the military airlift fleet and then lease military airlift services to the private sector during peacetime. This would allow the government to recoup some of the expenses of maintaining the reserve airlift capacity needed for crises. Civil air carriers, however, have indicated that they would be far more interested in leasing a civil-style transport, for example during peak periods, than they would be interested in leasing a military-style transport because of the higher operating costs.

The possibilities that were further explored are:

- Make participation in CRAF compulsory for all air carriers.
- Expand the breadth of business offered in exchange for CRAF participation.
- Provide direct payments annually for enlisting in CRAF.
- Provide an activation surcharge.
- Adopt a voluntary program with no precommitments.

Make Participation in CRAF Compulsory for All Air Carriers (Option 1)

At one extreme, participation in CRAF could be made compulsory. For a major national emergency, the President could be provided emergency powers that would allow the federal government to take charge of those airlift services that might be required to deal with the emergency. The government would draft needed resources, and during the period of the draft it would regulate market shares to protect air carriers whose assets had been called upon during the crisis.

This approach has at least three major difficulties. First, although the government might be able to regulate domestic market shares as it once did under regulation of the airline industry, it would be a different matter to protect U.S. carriers on routes where they compete with either foreign carriers or U.S. carriers with joint operating agreements with foreign carriers. Second, this measure reopens old arguments about regulation of the airline industry. Finally, the major airlines, for example, could be expected to resist such a move unless they could be assured of a level playing field. However, we found no satisfactory way to level, both in fact and appearance, the playing field in such a diverse industry so that unfair advantages are not gained during an emergency activation. For example, of two competing air carriers in a particular market, one may have aircraft that could support an airlift operation and the other may not.

Expand Business Offered in Exchange for CRAF Participation (Option 2)

This option has two variations. One involves shifting more international cargo to CRAF participants, the other expanding the services CRAF carriers could perform for the government.

Shift Defense Department's International Cargo to Civil Air Carriers (Option 2A). To explore the need for compensating for the decline in defense business for the CRAF carriers, we examined CRAF's historical experience to see whether there has been a correlation between the level of business and the number of aircraft in CRAF. Figure 3.16 plots the data for the past 20 years. While there may be a weak trend, the data are so scattered that it is probably unwise to attempt a forecast from this information. The number of aircraft offered is more likely to be influenced by carrier attitudes regarding the likelihood of another activation and the potential range of consequences for their operations.

Because 90 percent of military passengers on international travel are already carried by CRAF carriers, the main international opportunity for further business is cargo airlift, for which CRAF carriers handle only about one-fourth of the demand. Figure 3.17 examines the ability of such a shift in cargo to compensate for a decline in DoD's international travel. For a given level of business, as a percentage of the 1989 level (here assumed to have been $500 million), the left panel shows the dollar amount lost while the right panel displays the amount gained from a 30-percent shift and alternatively a 70-percent shift in the cargo that the military transports would otherwise carry. For example, assume an overall level of business that is 50 percent of the 1989 level. The loss in passenger and cargo business would be $250 million.

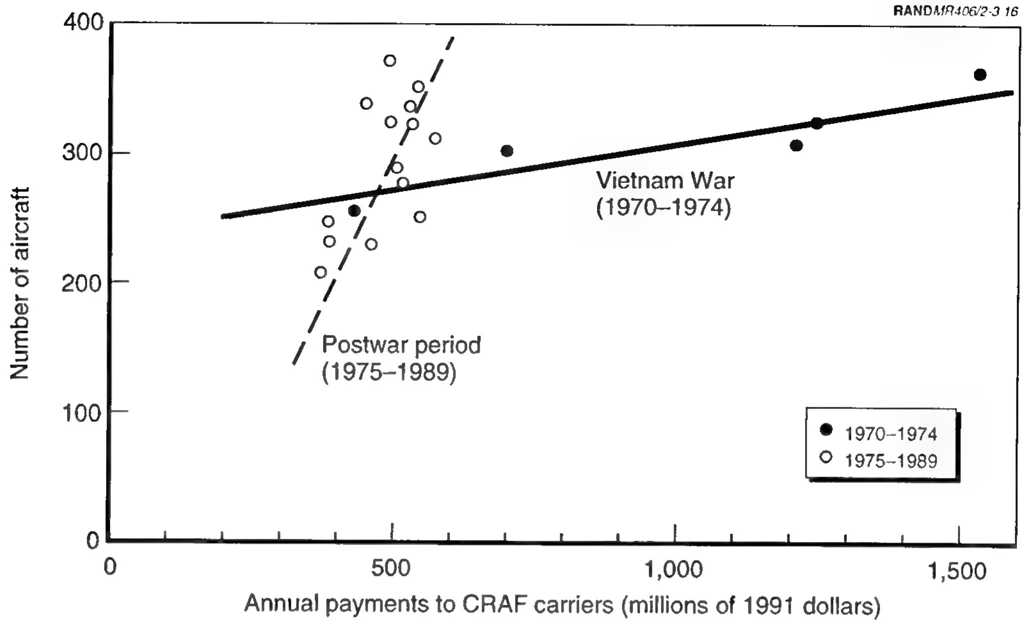


Figure 3.16—Influence of Annual Payments on Number of Aircraft Committed to CRAF Stage III

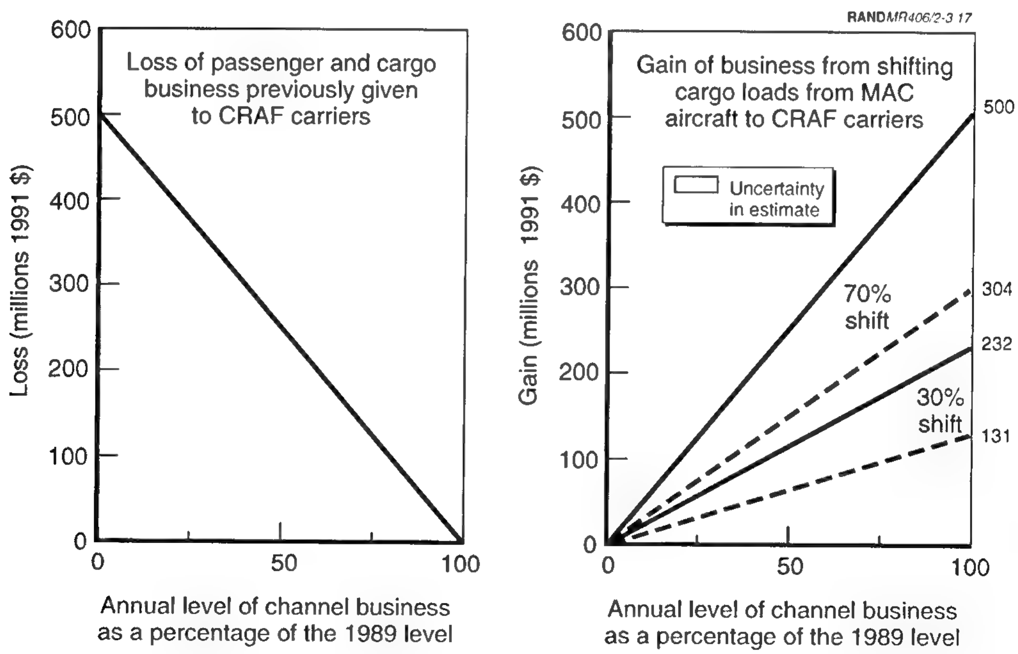


Figure 3.17—Compensate for Decline in Channel Business by Shifting Cargo from Military to Civil Transports

Consider the case where 70 percent of the cargo that military transports would otherwise carry is shifted to the CRAF carriers. The right panel shows that such a shift could generate $250 million only if all of the optimistic assumptions are used in the calculations.

On the other hand, if force reductions cause 1989 business levels to shrink by more than 50 percent, Figure 3.18 shows that shifting cargo alone cannot fully compensate. The figure shows the sensitivity of the amount of cargo that must be shifted to compensate for declines in business provided to the CRAF carriers. As in the previous chart, the band represents the range of uncertainty in our calculations. The chart shows the sensitivity for a range of declines in business as a percentage of the 1989 level. Especially noteworthy is the shape of the curve. Given uncertainties in the calculations and the steepness of the curves, it is clear that shifting cargo could be relied upon for only moderate relief of lost business. The cost to the Air Force of providing that relief, however, could be quite high if the Air Force would be deprived of opportunities to use its transports during peacetime in ways that provide flying hours both for proficiency and training purposes and for transporting cargo, for which the AMC is compensated by the using organizations.

Include Additional Government Air Travel Within the CRAF Program (Option 2B). The second variation of this option would bring more government airlift services within the purview of the CRAF program:

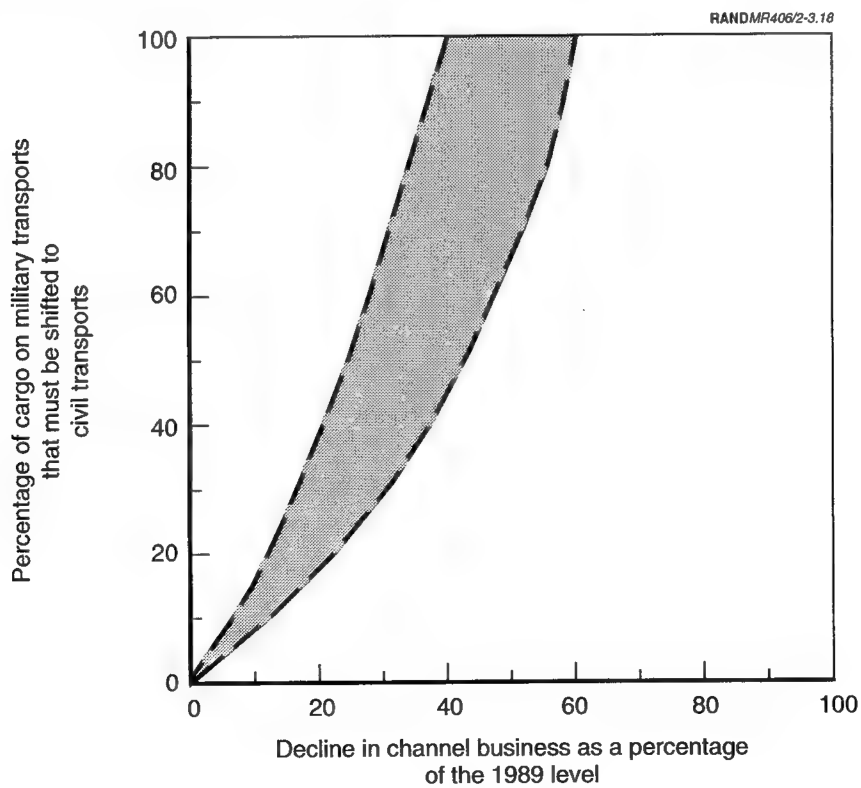


Figure 3.18—Shift Required to Compensate for Decline in Channel Business

- Airlift now managed by the GSA might be linked to the CRAF program.
- U.S. postal service business might be linked to the CRAF program.
- The domestic cargo airlift services now being provided by private-sector firms to the DoD might be linked to the CRAF program.

We failed to find, however, an easy way to accomplish this, because we foresaw serious conflicts with established objectives and policies of other government interests, as well as probable resistance from the large air carriers. For example, many air carriers do not have any of the long-range international transports the DoD needs, but they compete with air carriers who are using such transports in markets where they are vying to maintain the loyalties of the same customers.

Provide Direct Payments Annually for Enlisting in CRAF (Option 3)

Another possibility would be for the government to contract in advance for the commitment of specific airlift resources. The government would pay directly for an entitlement to activate particular aircraft and associated air crews. Such an annual payment could supplement the peacetime business offered to the CRAF carriers. The size of the payment could be established to help offset the decline in the military's need for peacetime airlift, and to better reflect the carrier's costs and risks associated with participation in CRAF.

Make Payments to Offset Declines in Defense Business (Option 3A). The government could initiate an approach that would stabilize CRAF carrier revenues to cover their fixed costs at the 1989 level. We define the nonfixed costs (variable costs) to include fuel, food service, and salaries related to flying operations. Figures 3.19 and 3.20 depict a scheme whereby carriers would receive a surcharge to compensate for loss of revenue regarding their fixed costs as a function of declines in the level of business offered to the CRAF carriers.[20]

For example, suppose business falls to half of the 1989 level; Figure 3.20 shows that the Air Force would purchase $250 million of airlift services from the carriers and pay an additional surcharge of $147 million to compensate for the decline in business. That would amount to a 60-percent surcharge rate.

Use a Sealed-Bid Process to Set Payment Levels (Option 3B). A direct-compensation approach might be implemented in the form of periodic sealed bids to government requests for commitment of particular services, such as 747 freighters or wide-body passenger transports. The carriers would bid on the surcharge percentage that they would require and/or the amount of the annual payment.

Another variation on the direct-payment approach would be to have air carriers periodically submit offers for emergency airlift services. Each carrier would tell the government how many aircraft it would provide at a price specified by the air carrier

[20]The surcharge, in addressing only fixed costs, excludes variable costs, such as fuel and flight crews.

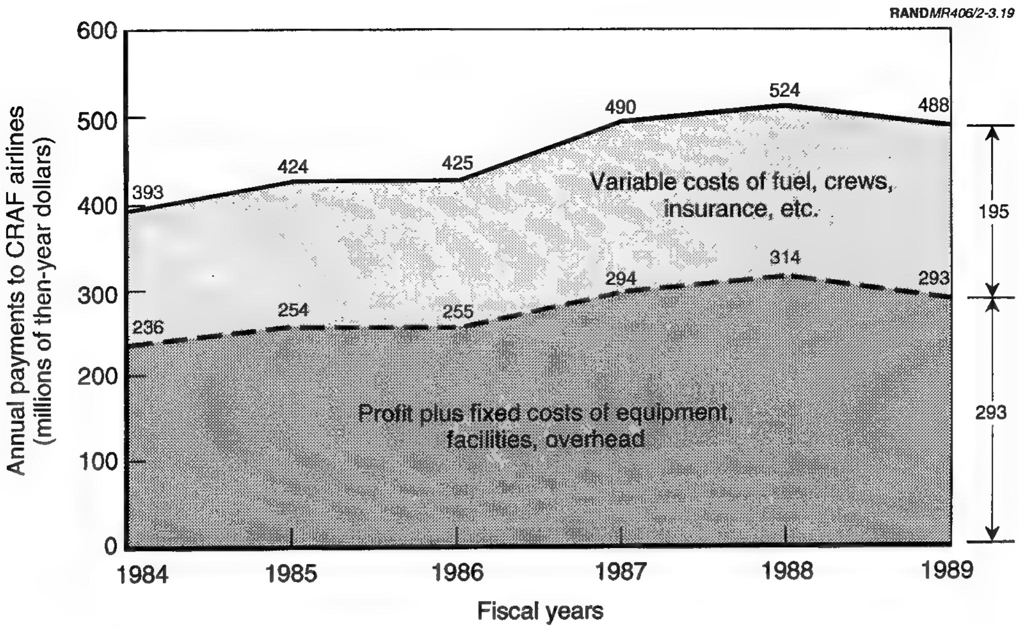


Figure 3.19—An Alternate Incentive: Direct Compensation to Guarantee 1989 Level of Payments for Fixed Cost Plus Profit

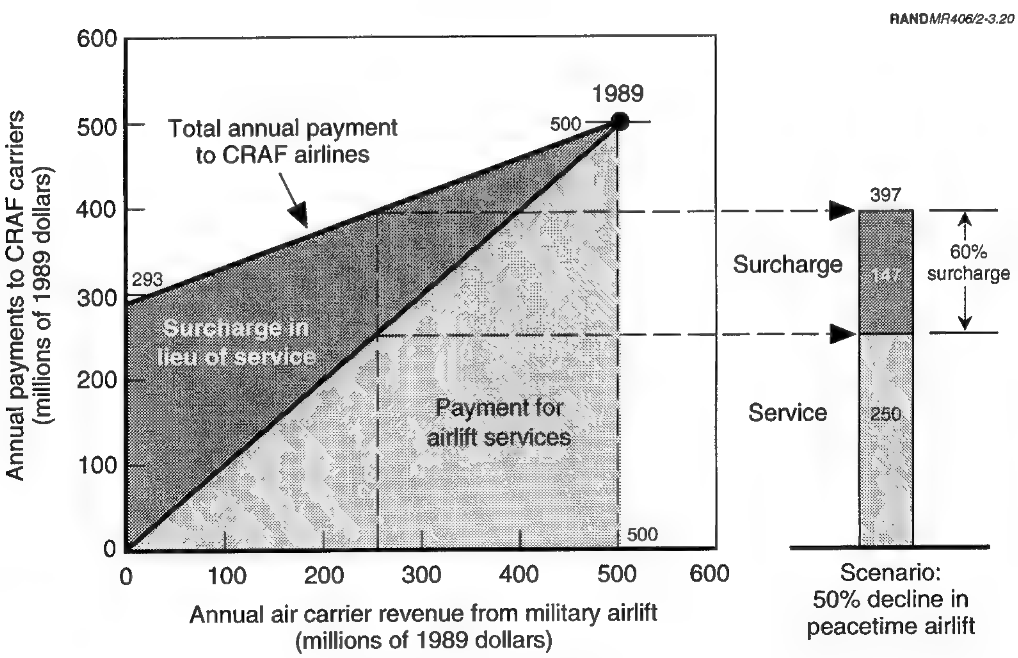


Figure 3.20—Cost of Direct Compensation Incentive as CRAF's Peacetime Business Declines

in its offer. Using the lowest-cost bids, the government would then accept into the emergency fleet those types and quantities of aircraft that it deemed necessary and appropriate to meet its emergency airlift needs. Air carriers could then be awarded mobilization points in accordance with the capabilities and quantities of aircraft that were accepted into an emergency civil airlift program. The government could explore using such mobilization points as a matter to be considered in awarding air-travel business, new international routes, gates at airports, air-traffic–control priorities, etc. By allowing air carriers to sell or otherwise trade mobilization points, the general appeal of participation in an emergency civil airlift program alternative to CRAF could be enhanced.

A potential drawback of such methods that provide direct payment (Options 3A and 3B) is that it might appear that the government was subsidizing the air-carrier industry. Economists, however, are divided on this subject. Some economists are unconcerned, because the government is involved in subsidies in many other areas. However, the matter of subsidies for the transportation sector has been the subject of significant public debate in the past. For example, when Pan Am sought government subsidies to offset subsidies that foreign air carriers were receiving from their governments, it failed to obtain the necessary support. One of the issues that arose in that debate was whether the government should subsidize a company that some believed was in need of better management. Thus, there is an issue about how successful the government might be in explaining why it was paying air carriers money for a service that might never be exercised.

Provide an Activation Surcharge (Option 4)

To reduce the problem of appearing to subsidize the air-carrier industry and to minimize the government's short-term expense, the carriers might be encouraged to take the substantial portion of their compensation in the form of a surcharge during periods of activation to provide the carriers compensation above and beyond the normal peacetime formula that was also used during the Gulf War activation. Given the low likelihood of activation, especially as long as there is a significant military airlift force, it may be in the government's best interest in the short run to encourage such a shift. For example, providing the air carriers during all phases of the Gulf War airlift a 50-percent surcharge would have increased the expense of that war by about $800 million.

If activation of CRAF remains a rare event, the risk of such a surcharge may be an acceptable course. If activation becomes more frequent, a direct-compensation approach might be implemented in the form of periodic sealed bids to government requests for commitment of particular services, such as 747 freighters or wide-body transports. The carriers might bid on the surcharge percentage that they would require and/or the amount of the annual payment. As with Option 3, there are two potential variations with Option 4, either set surcharge rates at fixed levels (Option 4A) or use a sealed-bid process to set surcharge rates (Option 4B). However, the implementation issue that arises is that the public may view large surcharges as war profiteering and fundamentally objectionable. Economists, however, are also divided on

this point. Whereas some see this as a serious political liability, others believe that argument is bogus. Whether activation surcharges, large enough to make a difference, would be accepted by the public remains uncertain.

Adopt a Voluntary Program with No Precommitments (Option 5)

As an alternative to the contracted-commitment approach, which requires air carriers to make commitments in advance of a crisis, the government might consider a voluntary system. Such a system could exploit market conditions at the time of a crisis. In time of emergency, the government would seek bids for those types of aircraft that were most needed. The voluntary concept is stimulated by the observations that

- Twenty-five percent of the civil transports used during the Gulf War airlift were already being used by the DoD before the Stage I activation.
- Eighty-one percent of the civil transports used during the Gulf War came from carriers supplying more transports than required.

The white areas in Figure 3.21 show significant numbers of aircraft volunteered by the civil carriers above what they would have been compelled to provide from activation of CRAF Stages I and II. The line depicting the 30-day average for the number of civil transports in use shows that there was significant excess capacity that could be called upon until the surge that occurred during December and January.

Small Air Carriers Offered a Lot More Transports Than Were Required by Their CRAF Commitments. As Figure 3.21 illustrates, the number of transports supplied

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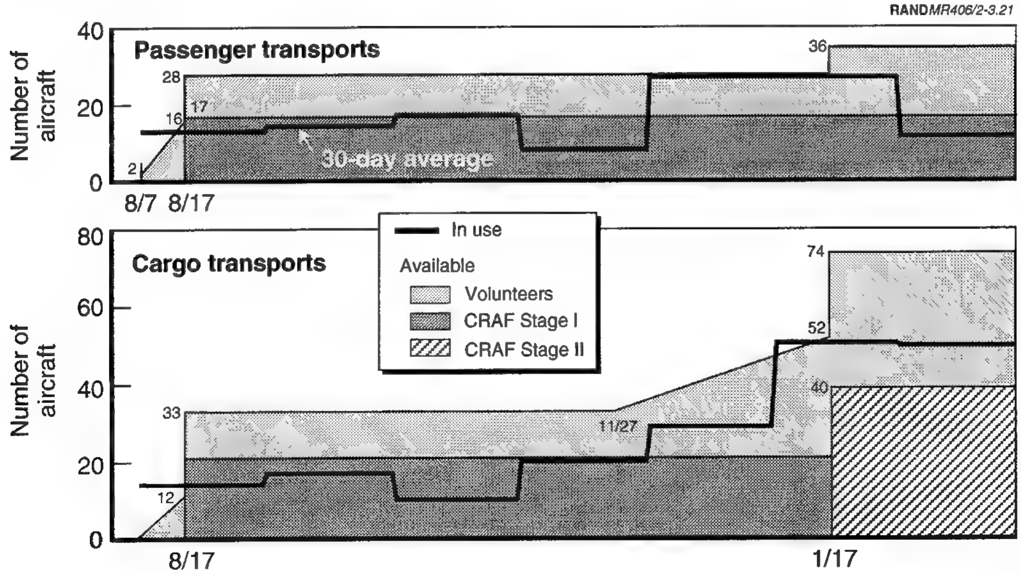

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igure 3.21—U.S. Civil Transports in Use Compared to Those Available to Support the Gulf War

by the CRAF carriers exceeded the number required by CRAF commitments during two critical periods: the first two weeks of the deployment and the months of January and February, when the air and ground wars occurred. On August 8, 1990, military transports departed the United States with the first units to be deployed during Desert Shield. Two CRAF DC-10 passenger transports loaded with troops and supplies also departed along with those military transports. By the time that CRAF Stage I was activated on August 17, a total of 28 CRAF passenger transports were already deploying troops and supplies.

During October and November, the need for passenger transports declined, and the Air Force released 12 of these 17 Stage I transports from service. They were recalled as deployment activity resumed during December.

To meet the airlift needs of early January, CRAF carriers contributed 41 aircraft above the levels required by the Stage I activation. By the time that Stage II for cargo aircraft was activated on January 17, the number of volunteer aircraft had climbed to 53 transports. Upon the Stage II activation, the total CRAF commitment reached 110 aircraft.

Regarding the Stage I activation, it may seem to have been unnecessary to call up passenger transports before November. What the figure does not show, however, is that many of the volunteered aircraft were narrow-body transports that were replaced by wide-body transports following the activation. A similar phenomenon pertains to the Stage II activation for cargo transports. Many of the volunteered aircraft were narrow-body transports, whereas many of the aircraft activated in CRAF Stage II were wide-body transports. Also, by the time that the Stage II activation occurred, much of the early January backlog of bulk cargo had been reduced. To have been most helpful, a Stage III activation would have had to occur during early January.

Was Activation of CRAF Really Necessary? These observations raise questions: To what extent was activation of CRAF really necessary, given the level of volunteer participation (Figure 3.22)? What if there was no activation? How would the carriers have reacted? Might they instead have competed for their "fair share"? Moreover, if premium rates were paid during the Gulf War airlift instead of the routine peacetime rates, how many more aircraft might have been offered voluntarily by either the carriers volunteering aircraft or the large air carriers who were concerned about their participation in the airlift?

Over the long term, there is a question about whether activation really needs to remain a feature of the CRAF program. What about an all-volunteer CRAF, even during emergencies? Certainly, there are levels of surcharges at which all carriers would participate fully. Moreover, if the surcharges become too high for the government to pay, the government could invoke emergency powers to control prices.

A voluntary system has the advantage that it would allow air carriers to respond in ways that are sensitive to the immediate state of the market rather than having to make long-term commitments. For example, during a major crisis, such as the Gulf War, some carriers may experience a greater decline in business than others and may

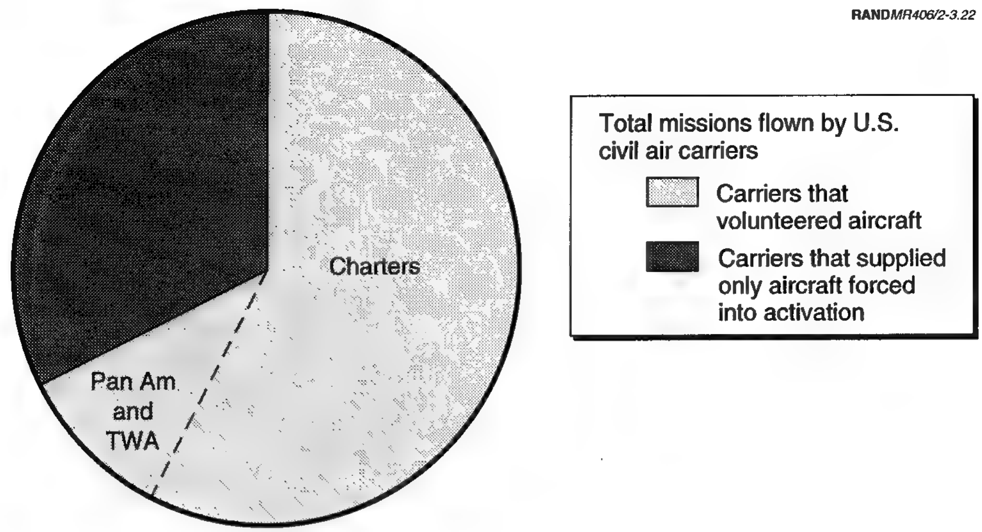

Figure 3.22—Civil Carriers Benefiting from Gulf War Airlift

therefore be more interested in offering to the government capacity that has become surplus. On the downside, such a spot market makes planning difficult and raises issues about the dependability of CRAF.

Because we found no obviously acceptable way to strengthen the CRAF concept to better ensure satisfaction of DoD's needs for civil-style transports, better management of the CRAF resources is next explored as the main opportunity for improvement. Then, Chapter Four explores the possibility of the Air Force operating civil-style transports.

REDUCING THE DEMANDS ON CRAF MAY INCREASE PARTICIPATION

Although each of the options has appealing aspects and long-term potential, none seems promising in the short term for implementation by AMC. One that AMC may be able to implement in the short term within its current authority is to achieve a better match between available incentives and committed aircraft by reducing the size of the CRAF program. Reducing the size of CRAF would allow the available incentives to more fully compensate the participating air carriers. It would also lower the potential level of disruption of civil transport services. Of course, it would also reduce the amount of airlift capacity that could be easily compelled to respond to a major emergency. However, this approach may be worthy of consideration, because only one-fourth of the CRAF-committed long-range international aircraft were actually used during the peak of the Gulf War airlift.

Elimination of Stage III May Be Helpful

The government can do two things to lower the perception of business risk involved in CRAF participation. It can reduce the expected frequency of a forced activation of

CRAF, and it can reduce the maximum exposure (e.g., drop Stage III of CRAF). It can do the former by making sure that it has enough organic assets of the right type and enough civil-sector assets that can be depended upon on a voluntary basis. If on the other hand, the government increases its expectations for CRAF, large air carriers can be expected to find participation in the current CRAF an increasingly unattractive business proposition. Thus, trying to shift the civil-military mix heavily to the civil air carrier side could actually undermine the government's ability to enlist civil carriers to join the CRAF program.

Continuing a large Stage III element may actually be counterproductive to recruiting a reasonably broad participation by the large air carriers. During the Gulf War, several companies lobbied to forestall a Stage III activation. The FY 1992 Stage III more than tripled the size of the air-carrier commitment and relied mostly upon the large air carriers. The political reality may be that a President would never activate Stage III unless there was the most serious of national calamities. In such a case, special authorization presumably would be forthcoming from either existing statutes or a special act of the Congress. Removing the threat of a large Stage III commitment may make large air carriers more willing to participate.

Freezing Stages I and II at Gulf War Levels May Help

During FY 1992, the government was in the process of significantly increasing the sizes of Stages I and II (Figure 3.23). Compared to the number of aircraft provided by carriers that seemed to benefit from the Gulf War airlift, the new Stage II asks for nearly double that number of aircraft. Because the size of the government's de-

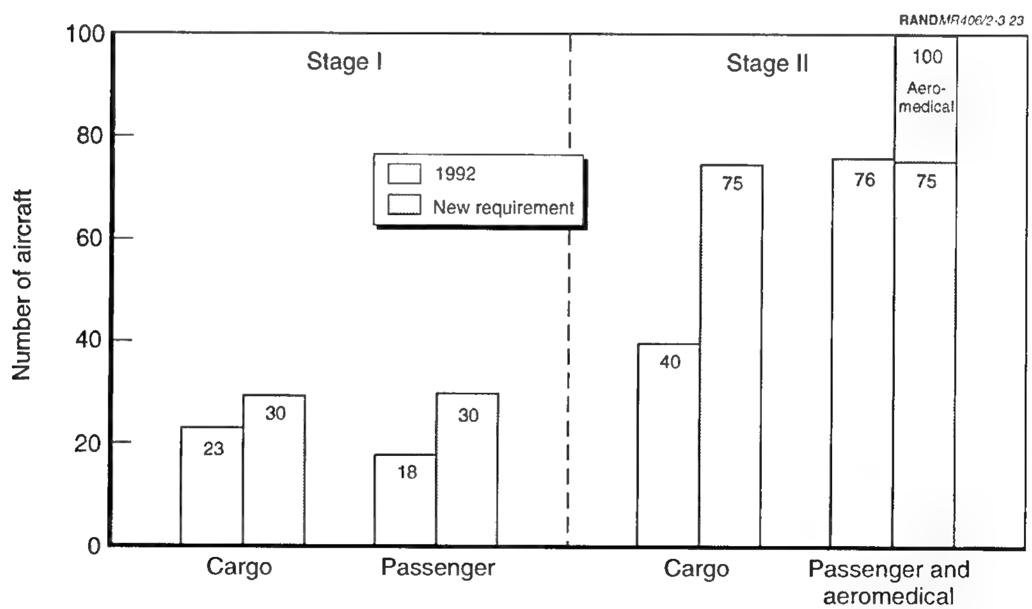

Figure 3.23—New Requirement for CRAF Raises Commitments for Air Carriers

mands may affect the enlistment in the CRAF program, both quantities and types of transports, it may be more beneficial to maintain the size of the Stage I and II commitments at their Gulf War levels. At those levels, it seems that three-fourths of the combined demand of activating passenger Stage I and cargo Stage II could be satisfied by air carriers actually interested in the business that a Gulf War–like airlift generates. However, this may depend heavily upon the existing economic conditions. On the other hand, with the new CRAF requirement, benefiting carriers from the Gulf War airlift could only cover the Stage I requirement (Figure 3.24).

IMPLICATIONS FOR MILITARY AIRLIFT

Maintaining the CRAF concept essentially as it has existed in the past hinges on the large air carriers believing that activations would be rare. To ensure that activations do not happen often, the DoD would need to maintain a level and composition of airlift capabilities sufficient to meet all but very large demands. To do this, AMC may need to operate some civil-style transports for efficient and sufficient movement of people and bulk cargo without activation of CRAF.

Regardless of the difficulties with its implementation, the CRAF program is a very cost-effective means of providing emergency airlift for those rare occasions needing very large amounts of airlift. As such, we recommend that DoD set realistic expectations for CRAF size and make sure that the military airlift fleet is large enough and versatile enough that CRAF would rarely have to be activated.

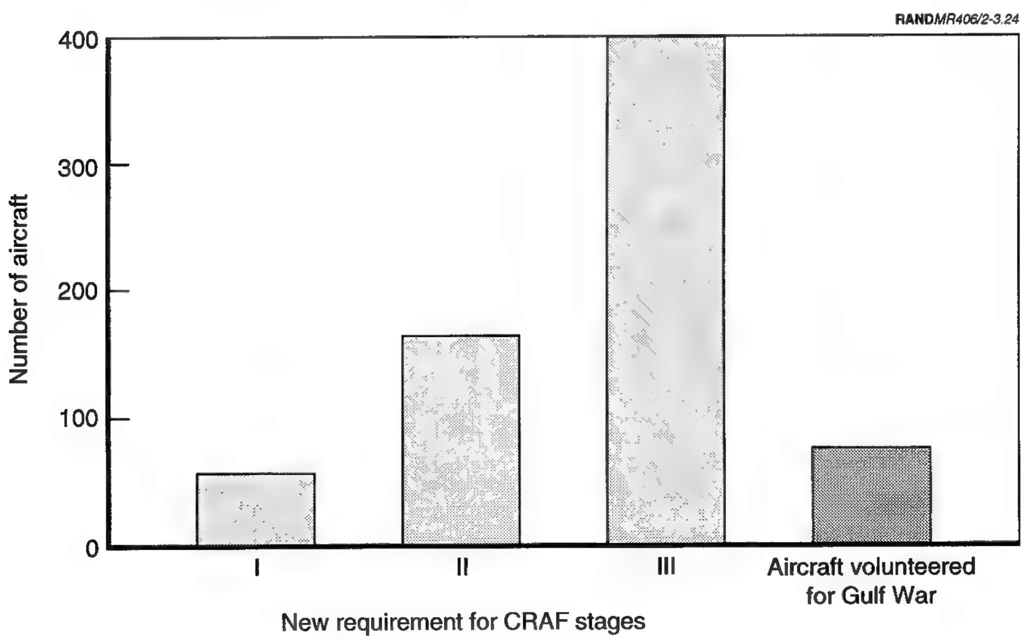

Figure 3.24—Benefiting Carriers Only Cover New Stage I Requirement

THE SUPPLY OF MILITARY AIRLIFT NEEDS TO CHANGE

The supply of military airlift that AMC produces for its customers needs to change in two ways. First, more airlift needs to be produced from current resources. Second, the impending retirement of much of the C-141 fleet provides an opportunity that must be used wisely to tailor both the level and the composition of the military airlift fleet so that the combination of the civil and military airlift fleets provides necessary airlift at the least cost.

Military airlift's historical levels of support for the acquisition and operation of its military transports can no longer be taken for granted, because deficit-driven budget pressures and the worldwide cutback in U.S. armed forces have brought every element of the defense budget under close scrutiny. Inheriting an aging fleet of C-141 and C-5A transports and KC-135 tankers, the new AMC faces significant modernization needs at a time when many of the Pentagon's investments in modernization are being scaled back. The command can expect close scrutiny of issues bearing on cost, affordability, and the comparative economics of alternative mixes.

Moreover, strains on the mobility portion of the Pentagon's budget will be particularly acute, because there are major investments under way for other dimensions of intertheater mobility—such as new expenditures on faster and greater-capacity sealift—along with increased prepositioning of materials aboard.

This chapter explores ways of getting more airlift from the current fleet and analyzes alternative mixes of the future fleet from a number of different aspects (see Figure 4.1). It begins by identifying the principal factors limiting the performance of the airlift fleet during the Gulf War airlift. It then describes the methodological approach developed to examine ways to increase the airlift produced by the current fleet and to evaluate different fleet mixes. It next analyzes how air refueling would affect the output of the current airlift fleet and evaluates five different mixes of aircraft. The final part of the chapter examines the C-17 program in light of conclusions drawn from the analysis of the fleet mix and considers the implications of choosing some of the five options analyzed.

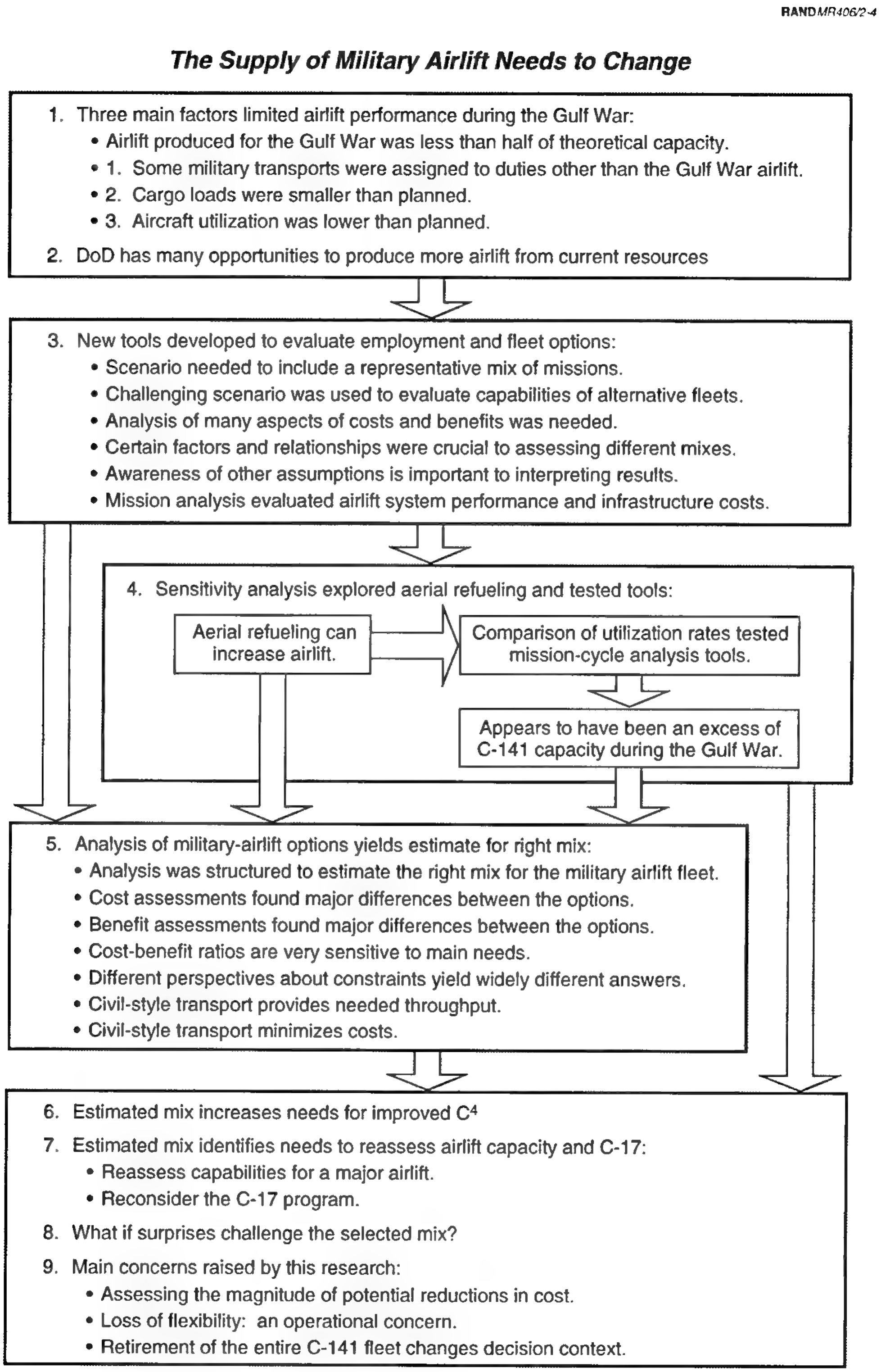

Figure 4.1—Flowchart for Chapter Four

THREE MAIN FACTORS LIMITED AIRLIFT PERFORMANCE FOR THE GULF WAR

The Gulf War airlift has provided a rich set of lessons about how to produce more airlift from the DoD's existing military transports. This report briefly sizes up the extent of the potential increase and focuses on the analysis of several of the significant issues that have an important bearing on estimating the right mix of military and civil airlift.

Airlift Produced for the Gulf War Airlift Was Less Than Half of Theoretical Capacity

During the peak month of the Gulf War airlift, the total amount of military airlift DoD produced amounted to less than half of the total theoretical capability calculated in Table 1.1. Although Figure 4.2 shows the C-5 producing one-half of its theoretical potential in support of the Gulf War airlift, the C-141 produced only about one-third, and CRAF only about one-fourth. Figure 4.3 shows that the production was even lower for the other months of the airlift. The Air Force reports that other sources show that the average daily airlift rate was 17 million ton-miles per day—compared to 13 in Figure 4.3—and the peak (for an unspecified period) was 33. The data in Figure 4.3 are from an Air Mobility Command analysis of data in its MAIRS data system (Ewing, 1991).

Of the factors used to calculate the theoretical airlift capacity, three account for most of the shortfall in the airlift in the Gulf War:

1. Some military transports were assigned to duties other than the Gulf War airlift.
2. Cargo loads were smaller than planned.
3. Aircraft utilization was lower than planned.

1. Some Military Transports Were Assigned to Duties Other Than the Gulf War Airlift

Review of Air Force records for the Gulf War airlift show that, on average, about three-fourths of the available military transports (C-5 plus C-141) supported the Gulf War daily. The remaining one-fourth was either assigned to other DoD duties or awaiting mission assignment.

Figure 4.4 takes this factor into account by only considering the theoretical capability of the resources actually allocated to the Gulf War airlift. Even after this adjustment, the application efficiency is still only 49 percent overall for the C-5 and 35 percent for the C-141. The overall amount of military airlift produced was less than half of the capacity that would be indicated by the theoretical daily airlift rates calculated in accordance with the planning factors in Table 1.1.

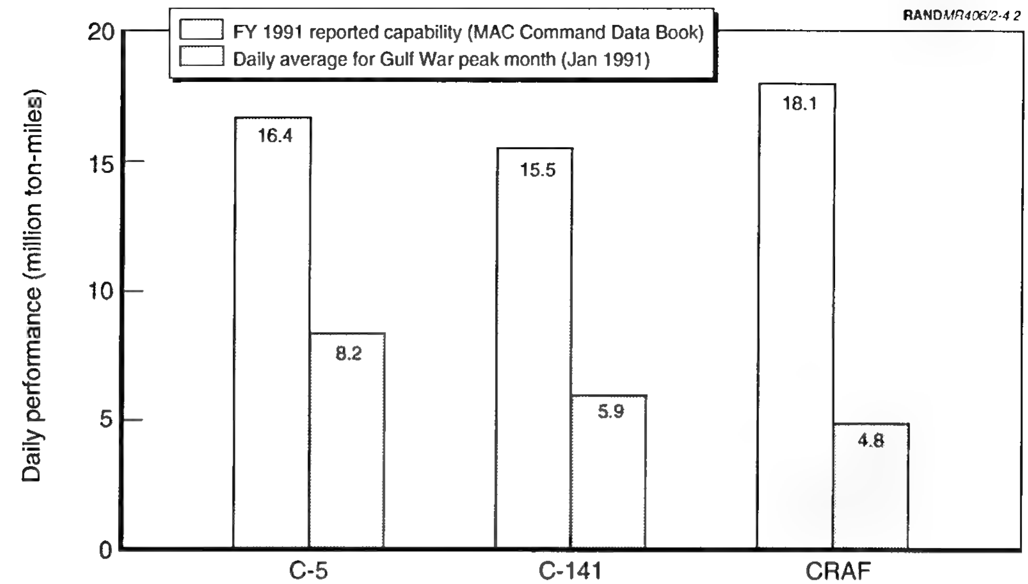

Figure 4.2—Only Part of the Theoretical Airlift Capability Was Used During the Gulf War

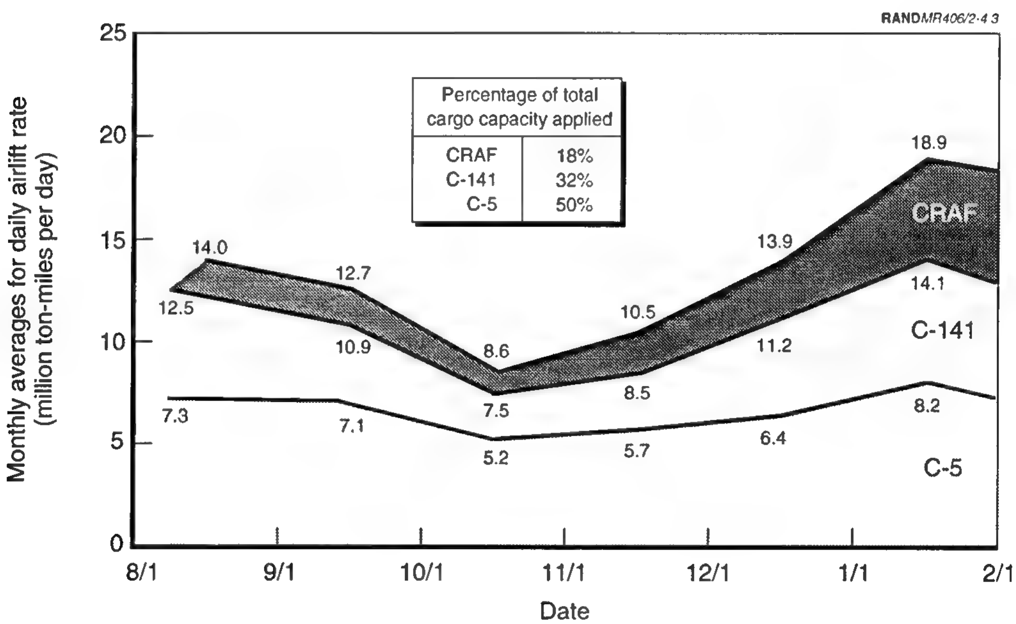

Figure 4.3—Application of Cargo Airlift Capacity Allocated to the Gulf War Airlift

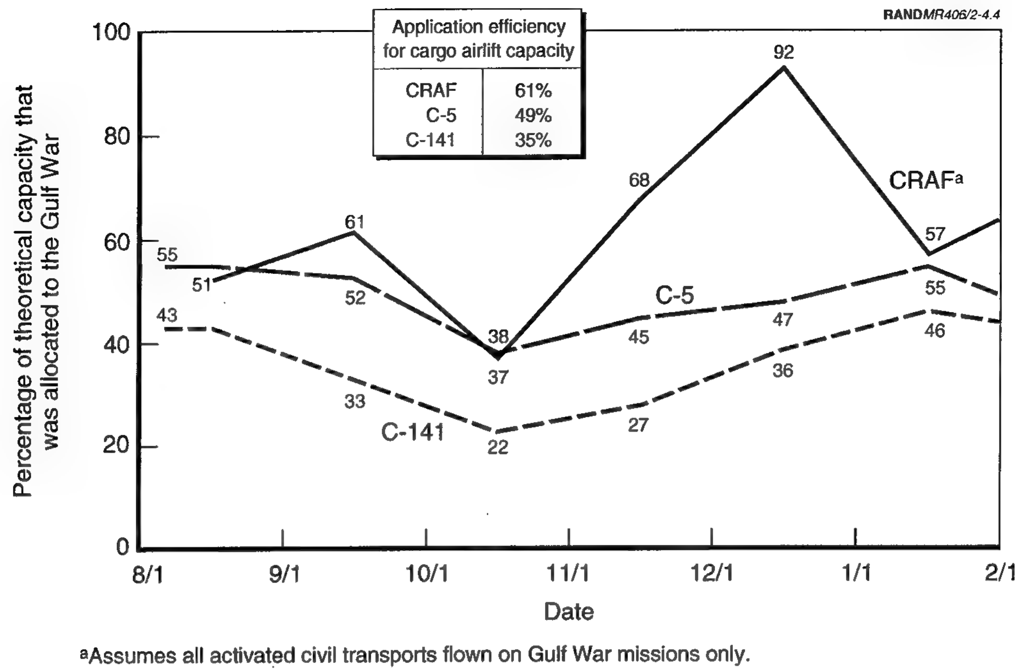

Figure 4.4—Application Efficiency for Cargo Airlift Capacity Allocated to the Gulf War Airlift

2. Cargo Loads Were Smaller Than Planned

Figure 4.5 shows that for the first 30 days of the airlift, the average cargo loads per mission were smaller than planned for all transports and particularly for the C-141 and the narrow-body civil transports. In other RAND research, Lund examined several frequently cited explanations for the shortfall experienced by the C-141.[1] The explanation most consistent with the data is the frequent application of a 20-ton payload limit, apparently in consideration of concerns about fatigue cracks that had recently been found in the wings of several C-141 aircraft.[2]

[1] Lund, Berg, and Replogle, 1993, pp. 58–65.

[2] A dissenting view is that the load limits for the fatigue problem were waived by Headquarters, MAC. Although the limit was officially waived, people within MAC may have nonetheless applied it to many missions. Another possibility is that a 20-ton limit happened to result coincidentally from other considerations, such as mission-planning factors (actual empty weights, actual fuel-consumption rates, possibility of headwinds, possibility of diversion en route, etc.). Although the precise causes of the smaller average loads may never be known with certainty, the bottom line remains the same. The average load per C-141 mission yielded monthly averages ranging from 16.7 to 19.4 tons. The overall average was 19 tons, which is 69 percent of the airlift planning factor (Table 1.1). One final observation: During the early months of the Gulf War airlift, RAND staff observed C-141 transports being dispatched to pick up deploying units based upon the assumption that the average load for each C-141 would be 20 tons.

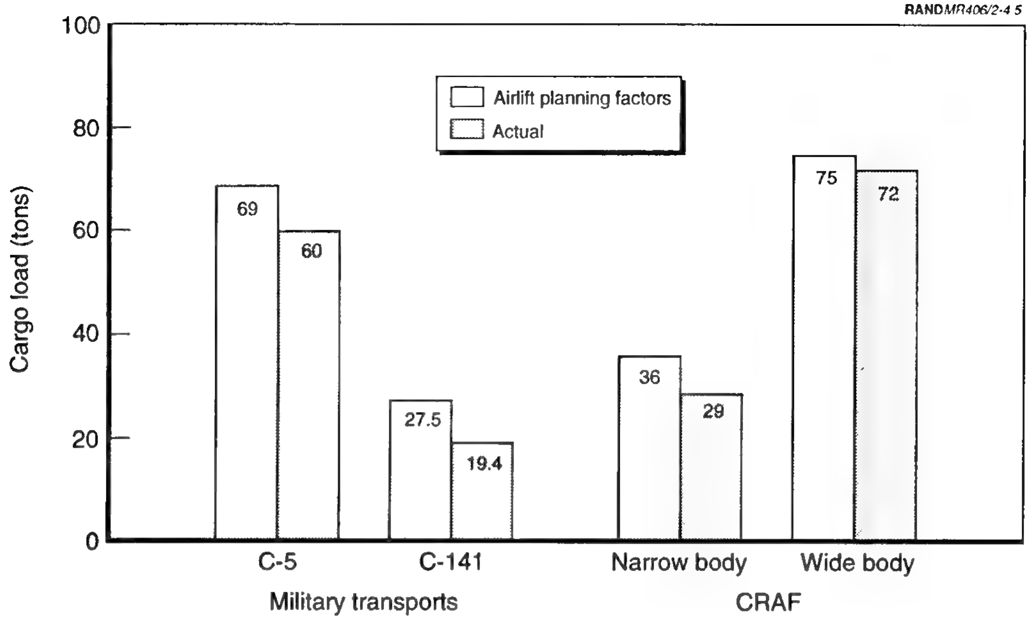

Figure 4.5—Average Cargo Loads per Mission During the First 30 Days of the Gulf War Airlift

Such a limit was not always applied, however, because some missions were flown with larger payloads.

Over the seven months of the deployment and the war, the three types of civil wide-body cargo transports (747, DC-10, and L-1011) averaged 74 tons per mission.[3] The C-5 averaged 62 tons; the DC-8 and 707 each averaged 25 tons; and the C-141 averaged 19 tons. The average loads for the C-5 and the C-141 fell short of the planning factors (68.9 and 27.5 tons, respectively) set forth in the USAF Airlift Master Plan (1983).

As an aside, it is interesting to observe that the average payloads achieved by the C-5 and C-141 are the same as those that would be planned for a mission with a critical leg length of about 3,700 n mi, given no wind and standard assumptions about loiter time at the destination airfield. Is it possible that Gulf War missions were planned with an equivalent critical leg of about 3,700 n mi, with no wind and standard loiter times to hedge against uncertainties, such as possible rerouting, headwinds, and unusually long loiter times at en route or destination airfields?

For the 30 busiest C-141 routes from CONUS to Europe during the Gulf War airlift, the critical leg length varied from 3,000 to 3,900 n mi, with a median distance of 3,400 n mi. Similarly, for the 18 busiest C-5 routes from CONUS to Europe, the critical leg

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[3]Throughout, "tons" is used to refer to short tons. The planning factor loads for the 747-200F and DC-10/L1011 are 112 and 71 tons, respectively.

length varied from 3,000 to 3,900 n mi with a median distance of 3,400 n mi.[4] Thus, many of the Gulf War missions had critical leg lengths of about 3,500 n mi between airfields.[5]

Did mission planning rules (critical leg length) contribute to the below-average payloads, or were the planning factors too optimistic about how much could be loaded within the available space of each transport's cabin? For the purposes of this analysis, we will assume that the latter was the case for the C-5. For the C-141, we assume that the fatigue problems led to the payload limitations. Because these assumptions give benefit of the doubt to the performance of the military transports, our analysis overestimates the capability of those transports if critical leg length was the dominant reason for the shortfall in payloads.

This issue deserves further attention, because if critical leg length is constraining payloads, the benefits of aerial refueling are greater than our analysis estimates.

3. Aircraft Utilization Was Lower Than Planned

Throughout the Gulf War airlift, the worldwide utilization rates for the military transports (Figure 4.6) were about half of the planning-factor rates used to calculate theoretical airlift capacity (Figure 1.4 and Table 1.1). Although the planning-factor rates in Table 1.1 (11 hrs/day for the C-5 and 12.5 for the C-141) are for a 30-day surge, the planning factors for the sustained rates (9 hrs/day for the C-5 and 10 for the C-141) are still substantially higher than the worldwide experience during the Gulf War airlift. Lund, Berg, and Replogle also examined the factors that contributed to the lower-than-planned utilization rates.[6] These included aircraft ready for a mission but awaiting an assignment due to congestion at APODs, longer-than-planned ground times during the execution of missions, airfield limitations that slowed the airlift system, and aircraft unavailable due to maintenance.

During the Gulf War and in subsequent analyses of airlift operations, the Air Mobility Command has preferred to examine aircraft use in terms of what it defines as the use rate rather than worldwide utilization rates. The use rate is the utilization rate for aircraft assigned to the Gulf War airlift. We encountered problems using this parameter, because we were unable to establish adequate visibility regarding the criteria used to decide when an aircraft was assigned to the Gulf War. Moreover, we lacked visibility regarding the seemingly large number of aircraft that at times were in the unassigned category: Why where they unassigned, what were they doing, etc.?

Ground Time Exceeded Planning Factors. Ground time included loading, unloading, refueling, delays for weather, and operational reasons, such as the need to meter the flow of aircraft into air bases (loading, en route, and destination) to match the aircraft-handling capacity of the bases.

[4]Lund, Berg, and Replogle (1993), pp. 63 and 64.

[5]For further discussion, see Lund, Berg, and Replogle (1993).

[6]Lund, Berg, and Replogle (1993), pp. 50–58.

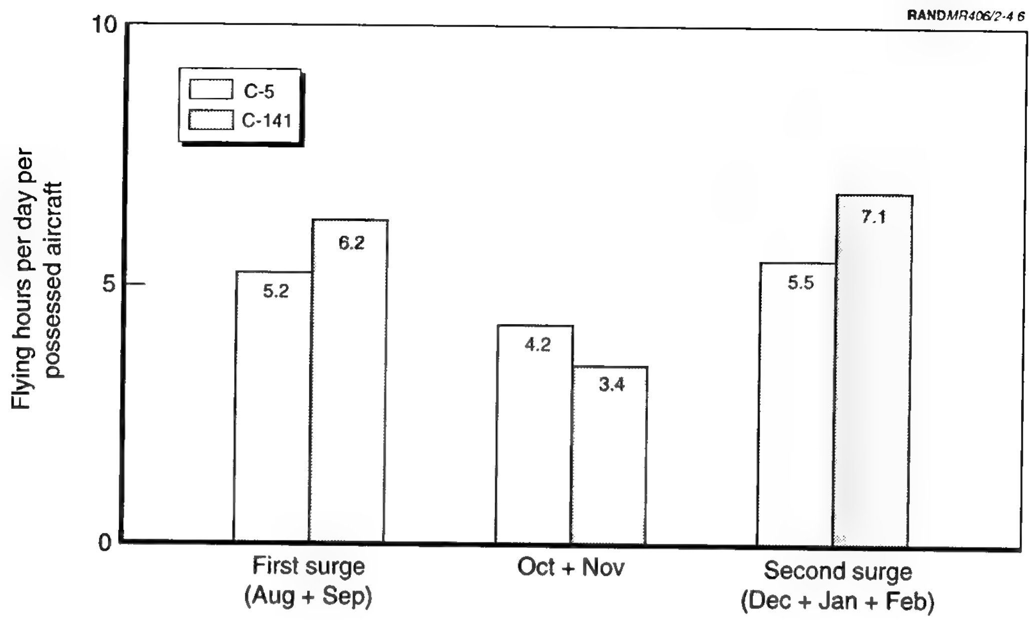

Figure 4.6—Worldwide Average Utilization Rates for Military Transports During the Gulf War Airlift

During the Gulf War missions (August 1990 through February 1991), the C-5 en route stops averaged 6.5 hours, twice the Air Force planning factor of 3.25 hours. The C-141 averaged 4.2 hours, nearly twice the planning factor of 2.25 hours.[7] Gulf War onload times also exceeded planning factors to a significant extent for both the C-5 (6 hours versus 3.75) and the C-141 (3.7 versus 2.75).[8] Offload times were closer to the planning factors: 3.6 versus 3.25 hours for the C-5 planning factor and 2.8 versus 2.25 hours for the C-141 planning factor.[9] The CRAF transports were closer to their planning factors.[10] Thus, the main sources of increased ground time were at the onload and the en route stops.[11] The increased ground times at the onload APOEs were due to limitations on the ability of units to load the transports they were assigned (Lund, Berg, and Replogle, 1993).

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[7]Median times were 4.3 hours for the C-5 and 2.9 hours for the C-141.

[8]Median times were 4.2 hours for the C-5 and 3.0 hours for the C-141.

[9]Median times were 3.2 hours for the C-5 and 2.3 hours for the C-141.

[10]The planning factors, means, and medians for the narrow-body transports were 2.0, 2.7, and 2.0 hours for en route stops; 2.5, 3.6, and 3.0 hours for onload stops; and 2.0, 2.7, and 3.0 for offload stops. For the wide-body transports, the times were 2.0, 2.5, and 1.9 hours for en route stops; 4.0, 3.9, and 3.6 hours for onload stops; and 3.0, 2.8, and 2.5 for offload stops.

[11]The Air Force has attributed the increased ground time to congestion at the offload locations (APODs), which it believes could be reduced by using more APODs and using a recovery base in the theater for changing crews and servicing aircraft. The Air Force's analysis of its MAIRS data, however, shows that ground times at the APODs were close to the planning factors. We have neither performed an independent analysis of the ground time data nor have we assessed their validity. See Appendixes B and E in Volume 3 for further discussion of ground times and APOD utilization.

We analyzed the impact of these ground times for a notional airlift mission that included four stops: one for onload, one en route, one for offload, and one more en route. The results in Figure 4.7 compare the total ground time for servicing based upon two sources of information:

- Air Force planning factors (the "planned" case in Figure 4.7)
- Experience from Gulf War missions (the "actual" case in Figure 4.7).

Airfield Limitations Slowed the Airlift System. Space and supporting infrastructures at airfields at both the en route and destination locations were limited, and the loading of units took longer than mobility studies had typically assumed. This slowed the flow of all transports. Lund observed that the capacity of air bases to handle the flow of transports was a significant limitation on the utilization of those transports. Infrastructure limitations at air bases slowed the flow of transports throughout the airlift system.

APOEs had limited capacities for loading aircraft. Both Air Force and Army units found that they could not keep up with the initial flow of two transports per hour. The flow was reduced to one transport per hour to cope with a variety of underlying limitations, including poor coordination regarding the types and times for arriving transports, lack of training for personnel responsible for preparing loads and loading aircraft, limited availability of materiel-handling equipment, and limits on air base infrastructure, such as ramp space.

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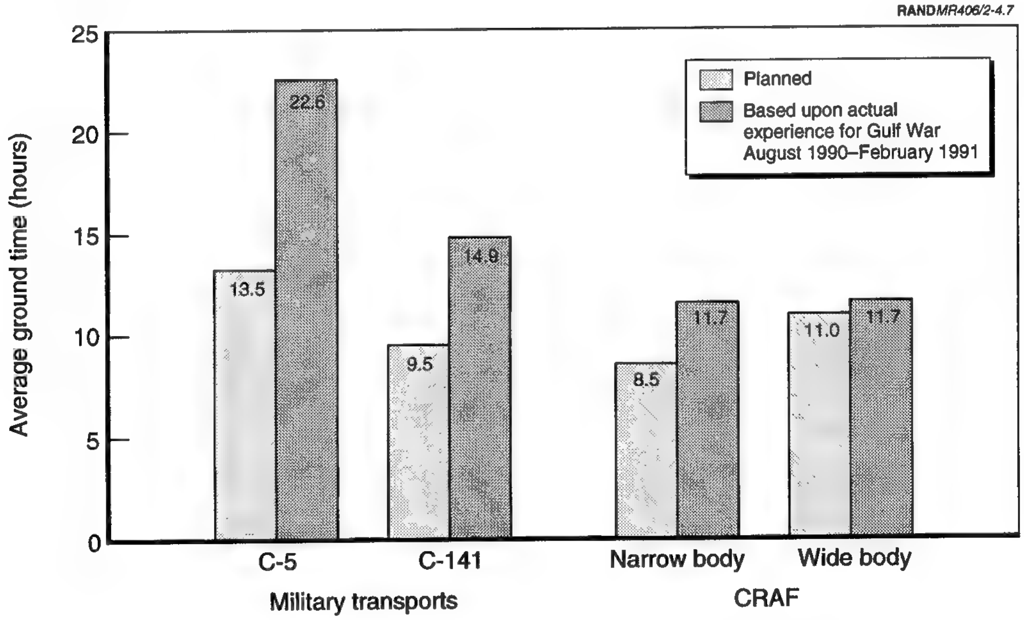

Figure 4.7—Average Ground Times for Servicing, Loading, and Unloading During the Gulf War Airlift for a Round-Trip Mission with Four Stops

En route bases and destination bases also had infrastructure constraints, such as ramp space and daily refueling capacity. The three main en route bases (Torrejon, Rhein-Main, and Ramstein) received about as many missions daily as the busiest in-theater destination, Dhahran (Figure 4.8).

Except for deploying Air Force units, which operated from many air bases in theater, the remainder of the Gulf War airlift missions arrived mostly at Dhahran. Dhahran could initially handle only about 30 missions per day because of constraints on its infrastructure (ramp space, refueling capacity, and materiel-handling capacity) and other uses at the airfield. Lund observes that "in late November, the Army was still requesting that over 75 percent of its missions go to Dhahran."[12] Later King Fahd and Jubail would receive 26 missions per day in contrast to the 8 per day earlier in the airlift. The capacity of Dhahran was also increased to 39 missions per day during December and January by reducing ground times and moving nonairlift functions elsewhere.

Because the flow of transports through constrained airfields can be increased by reducing ground times at those fields, we analyzed the Gulf War experience to identify the greatest opportunities for improvement. Using statistics from the Gulf War experience, we calculated the average total ground time per mission cycle for a notional

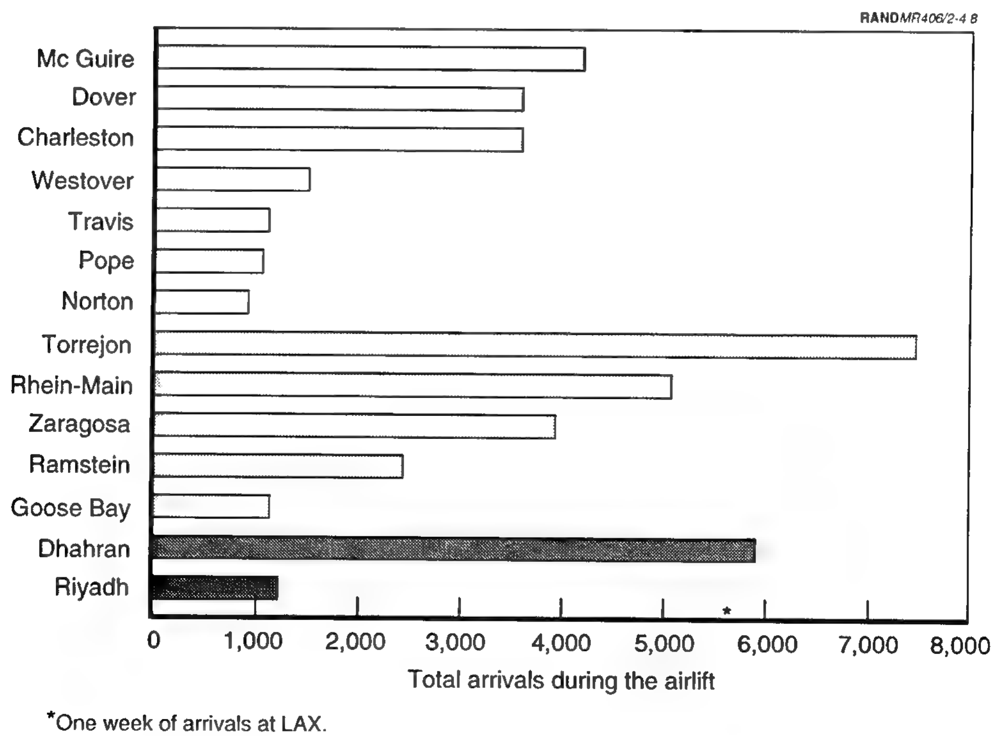

Figure 4.8—Air-Base Activity Was Intense During the Gulf War Airlift

[12]Lund, Berg, and Replogle, 1993.

Gulf War mission involving one en route stop in each direction. We then calculated the average total ground time using planning factors. The results in Figure 4.7 show that the C-5 accumulates more ground time per cycle than the other transports and that the C-5 has the largest excess ground time relative to that forecast by the planning factors.

To understand why the C-5 was accumulating so much more ground time in comparison to the C-141, we next analyzed the average distribution of time for a C-5 and a C-141 (Figure 4.9). The analysis focused on the aircraft possessed by operational units. Aircraft in the depot for maintenance were excluded. Figure 4.9 shows that, although the C-141 spent more time flying (36 versus 25 percent), comparable percentages of time were spent in loading, unloading, and the "other" category. Per flying hour, therefore, the C-5 was carrying a larger burden in elapsed ground time for loading, refueling, unloading, and crew change than was the C-141. Of course the C-5 is over twice as large as the C-141, so it is not unusual for it to require more time for loading, refueling, and unloading.

Figure 4.9 also shows that the C-5 carried a much greater maintenance burden per flying hour. It required over an hour of maintenance for every hour of flying, whereas the C-141 needed only a half hour of maintenance for every hour of flying. (Civil transports required even less maintenance.) Such demands for maintenance were reflected in the availability of the C-5 and the C-141 (Figure 4.10).

Other researchers identify further potential limitations on executing mobility operations, including limitations on aircrews and the lack of a current time-phased force deployment list (TPFDL) for deploying units. Although these factors did not emerge as significant sources of difficulty in our research, that does not preclude the possibility that their effects may have been hidden in the data that we analyzed. For example, the feasibility and value of current TPFDLs for deploying units is a matter that remains to be demonstrated and evaluated. Further, current TPFDLs may be key to necessary improvements in command, control, communication, and computers (C^4).

DOD HAS MANY OPPORTUNITIES TO PRODUCE MORE AIRLIFT FROM CURRENT RESOURCES

In this research, we focused on the question: How might the airlift system and the future mix of military transports be tailored to address the need to increase the production of airlift capacity from both existing and future airlift resources? Our analysis considered four force-employment possibilities that could increase aircraft utilization rates:

- Increase the number of airfields used to load deploying forces.
- Increase the number of in-theater airfields receiving forces.
- Reduce the time waiting for mission assignment.
- Reduce the number of en route stops to reduce ground time.

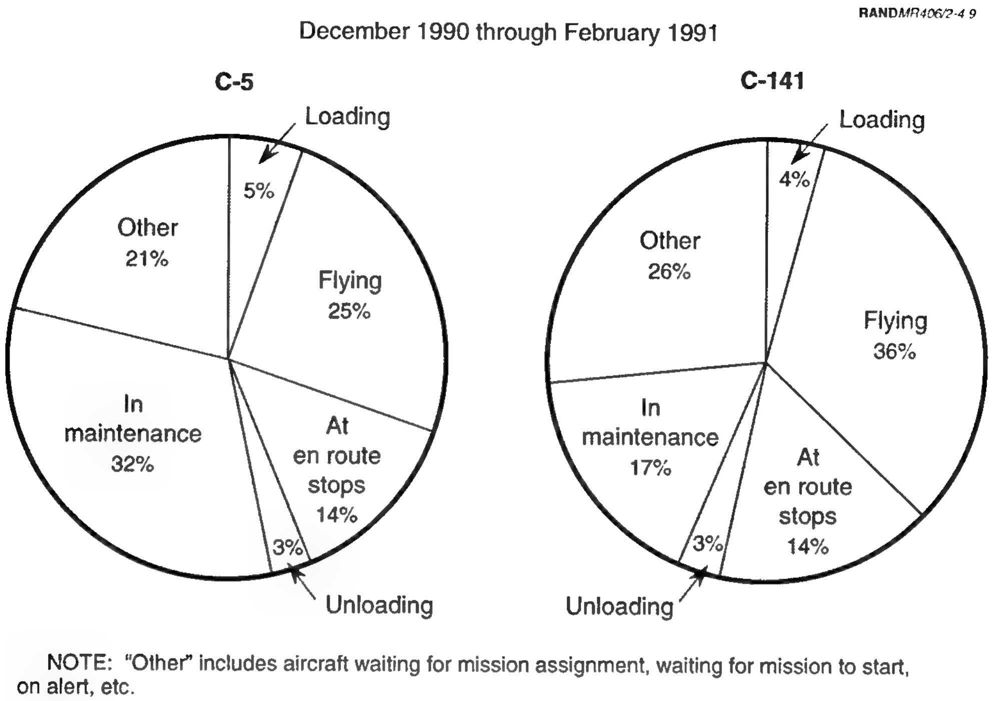

Figure 4.9—Distribution of Possessed Aircraft Hours During the Second Surge

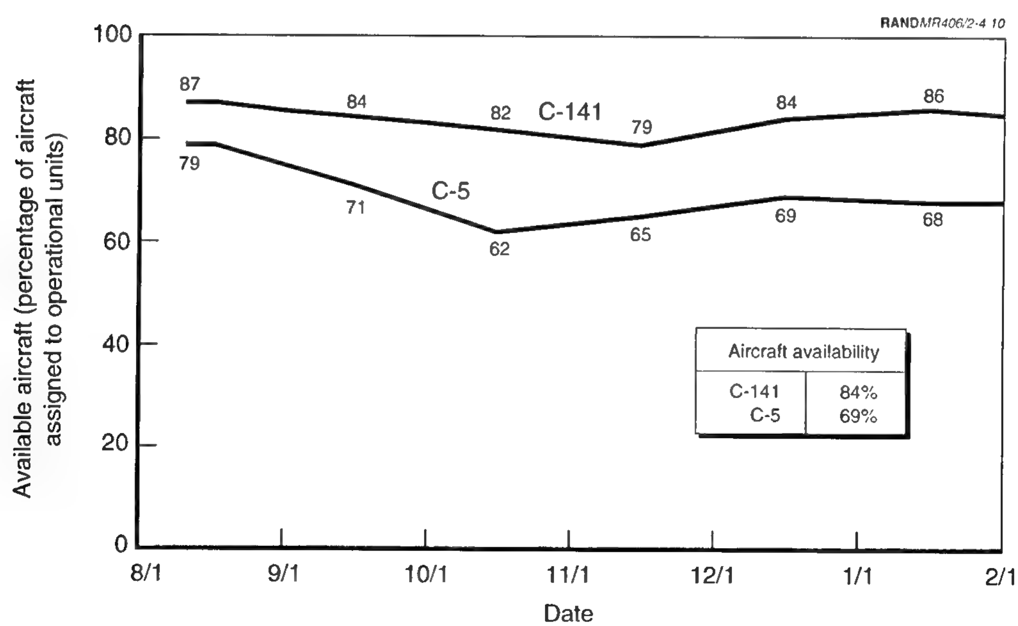

Figure 4.10—Aircraft Available for Missions During the Gulf War Airlift

We explore the effect of the first three approaches by structuring the scenario we used in our analysis, which we describe next, so that it includes multiple APODs and APOEs and reduces the time waiting for mission assignments. The fourth approach has two dimensions. The Air Force can reduce the number of en route stops either by using air refueling or by purchasing aircraft capable of longer flight legs. Subsequent sections of this chapter examine these two issues in some detail. We estimate that the C-5 and C-141 utilization rates could better their Gulf War experience by 10 percent and 100 percent, respectively. The C-5 improvement rises to 50 percent with the inclusion of aerial refueling.

NEW TOOLS DEVELOPED TO EVALUATE EMPLOYMENT AND FLEET OPTIONS

New analysis tools were needed to analyze concepts for improving utilization and to evaluate the comparative costs and benefits of options for changing the composition of the military airlift fleet. Unlike other research tools in the airlift area, the set of tools developed for this research captures many dimensions of airlift and tanker operations, aircraft performance, access to airfields (Chapter Five), and life-cycle costs.

To provide a context for using the tools, we developed a challenging scenario to test the concepts and options. We also developed a broad approach to the analysis that included many aspects of costs and benefits. To accomplish the analysis, certain factors and relationships were crucial. For example, our analysis needed to model certain considerations, such as aircraft utilization rates, mission cargo loads, aerial refueling, and round-trip mission times, because the differences between the alternative concepts and options are large enough to cause significant differences in these considerations—which in turn cause significant differences in estimated costs and benefits. Other matters could be treated more simply because the results were far less sensitive to how differences between the transports would manifest themselves in the calculated costs and benefits. The core of the analysis was provided by a new methodology that we developed to evaluate the mission performance of the airlift system.

Scenario Needed to Include a Representative Mix of Missions

The scenario needed to have certain attributes to allow for the development of a representative set of missions that would provide the analytical framework for the analysis. One attribute was that the APOEs should be distributed across CONUS. Because the payload-versus-range trade-offs for transport aircraft differ, and because a major airlift operation will draw upon units across CONUS, it is important to use at least a handful of different APOEs to avoid inadvertently picking a particular APOE whose distance from the theater might favor one transport type over the others. We also had set an objective of using enough APOEs to avoid the congestion the airlift system encountered during the Gulf War airlift.

The second attribute required to yield a representative set of missions was to address the movement of actual units, for which there are data about the level and composi-

tion of the loads to be moved and information about the airfields that would serve as APOEs. To avoid bottlenecks at APOEs and APODs, we assumed simultaneous deployment of multiple units to a set of APODs. Although such a pattern is common for the Air Force, it is not the Army's usual practice.[13] This assumption of multiple parallel streams of deployment had an effect on throughput that is equivalent to assuming unconstrained APOEs and APODs. This is not to say that infrastructure considerations should be assumed away. In our analysis, we calculated the infrastructure requirements of the alternatives rather than assume arbitrary constraints.

A Challenging Scenario Was Used to Evaluate Capabilities of Alternative Airlift Fleets

To assess the relative capabilities of alternative fleets under plausible conditions that would significantly stress the airlift system, we assumed a scenario involving long deployment distances and a significant amount of outsize materiel. To provide the distance, we selected Southwest Asia. To provide significant demands for outsize airlift, we selected a balanced deployment of units from the Army's five rapid deployment divisions identified in Figure 4.11, and we assumed no sealift and no prepositioning. Table 4.1 lists the Army's assessment for the outsize airlift that it needs to deploy these divisions.

This assessment scenario might represent a situation where a major deployment is required to an area that lacks easy access to seaports. During the early weeks of such a deployment, a balanced force of heavy and light units might have to deploy by air. The important feature of the scenario is that it provides a tough standard for measuring the capabilities of alternative airlift fleets. Because the airlift fleet needs to be optimized to handle the likely scenarios, as well as the broader range of situations for which the Air Force must be prepared, the assessment scenario is more demanding of the airlift system than are the more likely scenarios used in the Joint Staff Mobility Requirement's Study of 1992.[14]

Of the armed services, the Army has the greatest demands, both for airlift and for the movement of outsize materiel. Table 4.1 shows the Army's assessment of the amount of outsize airlift required to move the outsize materiel for each type of Army division depicted in Figure 4.11. (The 1st Cavalry Division is an armored division.) For each division the table lists the number of C-5 missions that the division would need in addition to the C-141 and CRAF missions. Clearly, the Army's heavy divisions (mechanized and armored) account for most of its outsize materiel and, for that matter, most of the DoD's outsize materiel. During the Gulf War, the heavy di-

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[13]During the Gulf War deployment, airlift resources were first focused on moving the 82nd Airborne Division and then moving the 101st Air Assault Division.

[14]For that study, most of the materiel for the heavy divisions was prepositioned or carried by sealift. In recent analyses, the DoD has sought to select airlift and prepositioning programs that complement one another to provide for military requirements at the least cost. DoD staff recently reported that their analyses to date have found that, if we preposition the right mix of equipment and supplies, the cargo to be moved early in a deployment is predominately oversize and outsize. Our analysis did not examine prepositioning.

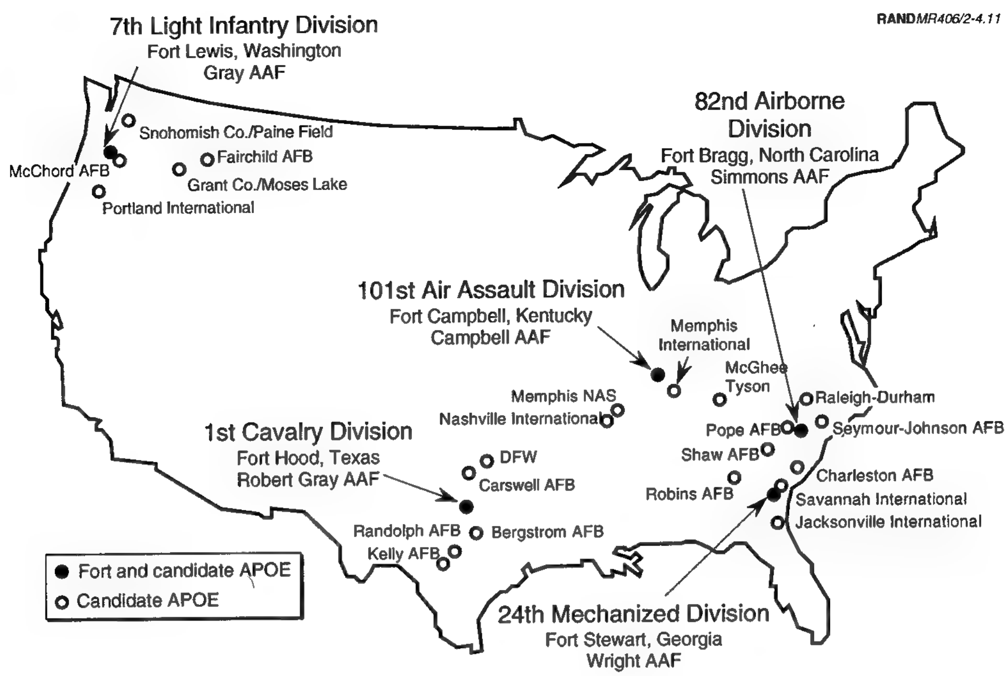

Figure 4.11—Deploying Units and Their Aerial Ports of Embarkation Assumed for the Southwest Asia Scenario

Table 4.1

Overview of Demands for Outsize Airlift When Deploying U.S. Army Divisions by Air

Type of Unit	C-5 Missions Required
Divisions, when moved exclusively by airlift	
Airborne	21
Air assault	82
Infantry	18
Mechanized	757
Armored	787

visions were sent by sea, and in the future more of the equipment for the heavy divisions are planned to be prepositioned on ships at sea. Thus, by including two heavy divisions in the five-division deployment scenario, we are using one of the most outsize-intensive deployments that could be assumed, to evaluate the ability of alternative airlift fleets to handle a wide range of situations.[15]

[15]Deployment of Patriot batteries, as was done during the Gulf War, also places demands on outsize airlift capacity. Bowie (1993) examines a scenario requiring ten batteries to be deployed over a 30-day period to provide theater missile defense for a major regional contingency. Depending upon the number of

We chose to focus on the movement of the Army's five rapid-deployment divisions for two reasons. First, the Army was the largest user of Gulf War airlift missions. Of the 8,820 deployment missions, 46 percent were assigned to the Army. Much of the 6,281 resupply missions were also in support of the Army. Second, this would provide an opportunity to demonstrate the potential value of a simultaneous deployment of Army units that might allow for more rapid future deployments. During the Gulf War airlift, the sequential delivery of Army units and their supplies was constrained by the rate at which they could be loaded at the APOEs and the rate at which they could be received at the main APOD at Dhahran. We did not examine the case of moving one division at a time, because the APOD serving each division could not handle the number of available transports.

Located across CONUS, the Army's five rapid-deployment divisions offered the analytical advantage of presenting the airlift fleet with a wide mix of different types of loads. While some units are light on outsize materiel, others are quite a bit heavier. Moreover, since most outsize materiel comes from the Army, this would be a good test of the ability of the alternative airlift fleets to handle needs for outsize airlift. Because the heavy divisions (such as the 24th Mechanized) have significantly more outsize equipment than the other divisions, this assumption tends to create a worst-case situation in terms of demands for outsize airlift capacity.

In Southwest Asia, we assumed the availability of five airfields (Figure 4.12) that would serve as APODs for the deploying units. An APOD was assigned to each division:

- Dhahran for the 7th Light Infantry units
- King Khalid for the 1st Cavalry units
- Al Jouf for the 101st Air Assault units
- Tabuk for the 24th Mechanized units
- Thumamah for the 82nd Airborne units.

For the military airlift options considered later in this chapter, from 67 to 80 aircraft would arrive in theater daily, depending upon the fleet option. Because Dhahran's peak capacity was 39 arrivals daily during the Gulf War airlift, at least a second APOD would have to be opened to receive the materiel and personnel that the airlift fleet can deliver. During the Gulf War airlift, most Army units deployed to a single APOD at Dhahran, while Air Force units deployed directly to their operating bases. By using multiple APODs for the airlift, we avoided the congestion that occurred at Dhahran and contributed to the less-than-optimal performance of the airlift system during the Gulf War.

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launchers per battery, such a deployment would require from 50 to 130 C-5 missions. Such a demand for outsize airlift is within the capacity of the options considered by this research.

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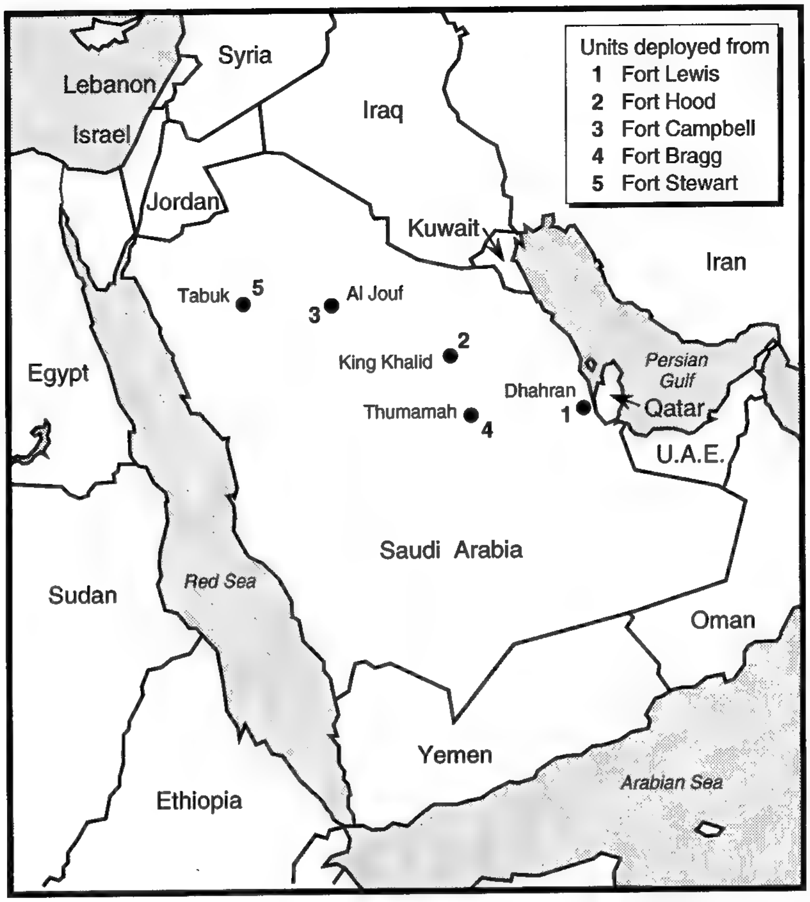

Figure 4.12—Aerial Ports of Debarkation Assumed Available for the Southwest Asia Scenario

Whether the Army would actually deploy its units to two or as many as five bases is not the central issue. The main issue is understanding the comparative costs and capabilities of different airlift fleets when they are used to move a mix of personnel and materiel from a mix of locations across CONUS to a mix of locations within a theater that is a long distance from CONUS. The reason that we assume specific units and locations is to provide a recognizable framework for calculating the comparative performance of the alternative fleets.

Because the other services also use airlift, we could have included them in the analysis, but we judged it unnecessary to a fair evaluation of the alternatives. Similarly, it would have been interesting to model the role of sealift, but we concluded that omission would mainly work to the disadvantage of the civil-style transports. However, by also examining the Gulf War mix of loads delivered by air we were able to perform a sensitivity analysis that compensates for our lack of direct treatment of sealift.

Finally, although it would have been interesting to analyze two different major regional contingencies, we chose to focus only on Southwest Asia to allow the opportunity to explore other seemingly more critical dimensions of the analysis. One potentially significant change that a Korean scenario might yield would be longer equivalent critical legs because of the distances between airfields and the usual presence of headwinds when flying to the west.

Analysis of the Many Aspects of Costs and Benefits Was Needed

Cost Assessment Had to Evaluate Needs for Many Types of Resources. In addition to the life-cycle costs of an airlift fleet, there are also costs in terms of the burdens that an airlift fleet imposes upon the airfield infrastructure. From the Gulf War experience, we saw that the important burdens on the airfield infrastructure were the ramp space that must be set aside for the airlift transports, the fuel that the transports consume, the crew members that must be accommodated, the servicing that each aircraft will require, and the additional support facilities that civil transports require. To evaluate these costs for each alternative airlift fleet, we used the following measures of life-cycle costs and average daily activity:

- Life-cycle costs for 25 years (FY 1993 through FY 2017), expressed in 1992 dollars.[16]
- Ramp space allocated to unloading and servicing transports upon their arrival in theater
- Fuel consumed—round-trip—by all transports and tankers[17] assigned to the airlift scenario
- Number of crew members arriving in the theater that would need accommodations for crew changes to occur in theater
- Number of civil transports arriving in theater that would need the additional support facilities peculiar to civil transports
- Number of total transports (civil and military) arriving in theater that would need support.

Benefit Assessment Had to Evaluate Different Types of Benefits. In addition to the sheer tonnage an airlift fleet can deliver, two additional dimensions of airlift capability also need to be assessed and weighed in considering alternative fleets. The first is what type of materiel can be delivered. The second is where the materiel can be delivered. Regarding the first, the ability to deliver outsize materiel is a unique capability of some military transports, including the C-17. Regarding the second, some military transports have the capability of delivering loads to airfields with short runways.

[16]Also expressed in 1992 present-value terms for two discount rates. Costs were evaluated with no discount rate and rates of 5 and 10 percent. Discounting, however, did not change the ranking of the options.

[17]Tankers were only used in one of the airlift fleet options. In that option, the tanker was used only to refuel transports.

To measure each of these dimensions of benefits for each alternative airlift fleet, we used the following measures:

- Tonnage of materiel that could be delivered directly to airfields with short runways (less than 5,000 feet long, but at least 3,000 feet)
- Tonnage of outsize materiel that could be delivered to the theater
- Total tonnage of materiel that could be delivered to the theater.

We chose 5,000 feet to distinguish the different capabilities of the C-17 and the C-5. The minimum-length runways for the C-17 and the C-5 are 3,000 and 5,000 feet, respectively, for most militarily meaningful loads.

Certain Factors and Relationships Were Crucial to Assessing Different Mixes

To produce reasonable estimates for the cost and benefit measures, certain factors and relationships needed to be addressed to link the significant characteristics of alternative transports to the costs and benefits. Failure of past analyses to address such matters fully has contributed to inflated expectations of airlift capacity and explains, in part, why the amount of airlift produced for the Gulf War was so much lower than what planning factors had suggested. Our analysis gave close attention to the three considerations chiefly responsible for the inflated assessments of airlift capacity for the Gulf War: (1) assignment of transports to needs other than the deployment of interest, (2) cargo loads that would be carried, and (3) utilization rates for transport aircraft.

Assignment of Transports Must Be Consistent Throughout the Analysis. In assessing the costs and benefits of alternative airlift fleets, we assumed that 75 percent of each type of aircraft was assigned to the deployment scenario of interest[18] and that the remaining 25 percent would either be applied to other needs or be held in reserve. The 75-percent rule was applied to each type of military and civil transport.[19]

No attrition of airlift assets, either accidental or hostile, was considered.

Cargo Loads Must Accurately Reflect Aircraft Characteristics. The load an aircraft can actually carry on an airlift mission is very sensitive to how far the aircraft must fly, the possibility of headwinds, the aircraft's performance capabilities, and the design of its cargo cabin. Because the Gulf War airlift yielded actual cargo loads that were less than the planning factors, this area needs careful attention. Moreover, many transports have airlift missions where the greatest distance between refueling, the critical leg length, is on the steep part of the aircraft's payload-versus-range

[18]As noted previously, this was approximately the case for the Gulf War airlift.

[19]Explicit and uniform assumptions are important. Some previous analyses, for example, have shown that a fleet of new airplanes could carry the load delivered by the C-141 in the Gulf War and do so much faster. A problem with interpreting such a comparison is that only a portion of the C-141 fleet was applied to the Gulf War airlift.

curve. This means that small errors in the calculation of the critical leg length, or wind, can yield large errors in the calculated payload. This makes such matters as headwinds and the manner in which fuel reserves are calculated important considerations in comparing alternative aircraft. A consistent and realistic set of rules must be applied to each aircraft. In this research, we adopted the following assumptions and rules:

- APOEs were used that allowed the transports to take off at their maximum gross weights for wartime operations.
- Mission routes were established for a Southwest Asia scenario using a nominal 3,500 n mi critical leg length. As noted previously, for the busiest routes during the Gulf War airlift, the median critical leg length was 3,400 n mi.
- No headwinds were assumed,[20] and fuel reserves were set in accordance with Air Force Pamphlet (AFP) 76-2.
- Cargo loads were set at the maximum level consistent with two constraints:
  - — Maximum payload from AFP 76-2 for a nominal critical leg length of 3,500 n mi
  - — Average cargo-deck loads (average weight of cargo per unit area of floor space) not to exceed the average deck load reflected in the AFP 76-2 planning factors for a nominal critical leg length of 3,500 n mi.

Utilization Rates Must Accurately Reflect Aircraft Characteristics. Because the Gulf War experience showed actual utilization rates significantly lower than the planning factors, we chose not to follow the practice of previous studies, which used planning-factor utilization rates.[21] This is a significant departure from past practices, because transport aircraft utilization rates are major determinants of airlift capacity, and achievable utilization rates vary widely for the aircraft of interest. To model the utilization of each type of aircraft, we found it necessary to view utilization as a function of mission route, sortie distance for each leg of the mission, flying time for each leg, maintenance needs, performance of maintenance, loading times, unloading times, ground delays for weather and air traffic, and flight-crew availability.

To model **flying time**, we analyzed each leg of every mission in terms of the leg distance and the average block speed the transport of interest could achieve. Block speeds were set in accordance with AFP 76-2, depending upon the length of each mission leg. If aerial refueling occurred during the sortie, the flying time was adjusted to account for the slower speed that must be maintained during the aerial-refueling process.

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[20]Headwinds are more of a factor for westbound deployments.

[21]During the initial surge, the worldwide average utilization rate for all C-141 aircraft assigned to operational units was 6.2 hours/day. Past airlift studies typically assumed a surge rate of 12.5 hours/day. The C-5 had a similar experience, with 5.2 actual versus 11 planned. The Air Force's goal for the C-17 was 15.65 hours/day. Since the completion of this research, the Air Force has reduced the utilization rates for the C-5 and the C-17 to 10.87 and 15.15 hours/day, respectively.

To model **maintenance needs and the performance of maintenance**, aircraft elapsed maintenance hours per flying hour were assumed to be the same as were observed during the Gulf War. In the case of the C-17, it was assumed that the elapsed aircraft maintenance hours correlate with the maintenance man-hours per flying hour. Elapsed clock time that aircraft spend receiving unscheduled maintenance was modeled using the following:

- For the C-5 and C-141, Gulf War average clock hours each type of aircraft spent in maintenance per flying hour (1.28 and 0.47, respectively)
- For the C-17, an estimate based on the goal for its maintenance man-hours per flying hour of an average 0.38 clock hours in maintenance per flying hour[22]
- For the 747, a conservative estimate based upon commercial aircraft experience of only 0.2 clock hours in maintenance per flying hour.[23]

Because aerial refueling reduces the number of takeoffs and landings required for a round-trip mission, one of the benefits of aerial refueling is a reduction in wear on systems that are stressed mainly during takeoff and landing.[24] Such systems account for about half of the unscheduled maintenance[25] that transports require. We assumed, therefore, that both half of the maintenance events and half of the maintenance time were driven by takeoff and landing and the other halves were driven by the simple accumulation of flying hours.

Ground time was modeled based on planning factors and tested with Gulf War experience. Ground times for loading, routine servicing, and unloading were modeled using planning factors being used by AMC at the time of the research (Ewing, 1991).[26] The sensitivity of the results was tested by using the observed ground times from the Gulf War.[27]

Delays were modeled based upon Gulf War experience. Weather delays, terminal handling problems, and en route traffic problems were represented by a modest

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[22]The maintenance experience with the C-5 and the C-141 was used to develop a relationship that links an aircraft's average hours in maintenance per flying hour to its maintenance man-hours per flying hour. This relationship was used to make a rough estimate for the maintenance clock hours per flying hour for the C-17.

[23]This assumption is consistent with the observation that some commercial air carriers have had routes where they have been able to sustain utilization rates of over 14 hours per day for this class of equipment.

[24]During the Gulf War, however, there were not enough transport crews qualified to make extensive use of aerial refueling.

[25]Although some of this maintenance occurs simultaneously with other activities, such as loading or unloading an aircraft, much of it does not. It is the latter class of maintenance activities that we address here.

[26]Grounds times (in hours) for the C-5, C-17, C-141, and 747-400F for loading and aircraft servicing were 3.75, 3.25, 2.75, and 4, respectively; for en route stops, they were 3.25, 2.75, 2.25, and 2, respectively; and for off-load and servicing, they were 3.25, 2.75, 2.25, and 3, respectively. The times for the C-17 were estimated by interpolating between the C-5 and C-14 based upon aircraft size, which presumably affects refueling and load-related activities.

[27]Subsequent to the completion of the research in 1992, the Air Staff has adopted slightly different factors for ground time (see Volume 3, Appendix B). Changes include 5 hrs for loading the 747, 2.25 hrs for 747-400F en route stops, and 2.25 hrs for each C-17 stop (loading, en route, and off-load).

amount of time included in the cycle time to account for the delays observed in the Gulf War deployment.[28]

To model **flight crew availability** (and crew member arrivals in theater), we assumed the following:

- The normal number of crew members per transport was six for the C-5, five for the C-141, and three for the C-17 and 747-400.[29]
- Flight crews were augmented for missions exceeding 14 hours of planned flying time.
- Flight crews could sustain no more than an average of 90 flying hours monthly.

Although individual crews can sustain higher levels of flying activity and did so during the Gulf War airlift, the average level that can be sustained by the total population of flight crews is less than the individual crew member limit. The difference is due to a variety of factors, including training, evaluation activities, and proficiency status.

Awareness of Other Assumptions Is Important to Interpreting Results

The other significant assumptions deal with the airlift system's infrastructure. The infrastructure at the aerial ports was assumed to be sufficient, and the magnitude of the burdens on that infrastructure was evaluated for both the transports and, in the instance of aerial refueling, the tankers involved in supporting airlift operations. We assumed en route bases were available, and we assumed tankers deployed to convenient bases from which they conducted aerial refueling missions. We assumed aerial refueling occurred in the vicinity of the bases from which the tankers operated and that the initial transports arriving at the APODs delivered airlift-control elements, ground support equipment, and materiel-handling equipment. Finally, we assumed flight crews would have facilities for rest at APOEs and APODs.[30]

Recent airlift analyses have tended to impose constraints on the maximum number of aircraft that can be on the ground at an airfield to represent the infrastructure capacity limitations at airfields. Rather than use such maximum-on-ground (MOG) constraints to represent infrastructure limitations, we thought it more informative to calculate the infrastructure requirements (ramp space, fuel, civil aircraft arrivals, etc.) and compare alternatives in terms of a set of considerations, rather than promote a particular consideration to the position of being a binding and absolute constraint. Our approach has the further advantage of providing a clearer result for the

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[28]Based upon Gulf War experience, the assumed delays for the C-5 and C-141 were 1.1 and 0.6 hours, respectively. Delays assumed for the C-17 and 747 were 0.8 and 1.1 hours; aircraft size was the main consideration underlying these assumptions.

[29]Both the C-17 and the 747-400 may be flown with a two-person flight crew. The third crew member could be a loadmaster.

[30]Otherwise, transports must make additional time-consuming stops to change crews.

reader. There is no question about what constraint might be limiting the performance of a particular option and thereby driving the outcomes of the analysis.

Moreover, this issue of measuring infrastructure costs rather than assuming constraints is especially important in this kind of analysis, where the differences in costs for the options can be much larger than the costs of relaxing constraints. For example, operational decisions can allocate more infrastructure resources (i.e., air bases and ramp space) for airlift, or investment decisions can allocate more funds for increasing infrastructure capacity, such as procuring additional ground loading equipment. Additional loading equipment, refueling trucks, etc., are far less costly than procuring additional aircraft.

Mission Analysis Evaluated Airlift System Performance and Infrastructure Costs

A spreadsheet was built for each mission cycle and each transport for each method of refueling. The resulting set of 120 spreadsheets examined the

- Five deployment streams (for example, see Figure 4.13)[31]
- Two mission cycle types for each deployment stream (one without a stop at a home base for maintenance and one with a stop)[32]
- Four transports (C-5, C-141, C-17, and 747-400F)
- Three methods for en route refueling (no air refueling, polar routes with aerial refueling, and great circle routes with aerial refueling).[33]

[31]As Figure 4.13 suggests, aircrews would be changed at the APOEs and APODs to minimize ground stops and to maximize the benefits of aerial refueling. In view of the large number of APOEs and APODs that are used to support a major airlift, such as that for the Gulf War, the Air Mobility Command is concerned about whether it is feasible to adopt a policy of changing air crews (including aerial-refueling-qualified crews) at APOEs and APODs, as is assumed in our analysis, instead of the current practice of changing crews at en route bases and at major home bases in the United States. Any implementation of crew changes at APOEs and APODs will increase the needs for improved command, control, communication, and computer (C^4) systems.

[32]Home bases for maintenance were Travis, Dover, and Altus Air Force Bases for the C-5. Home bases for the C-141 and the C-17 for maintenance were McGuire, Charleston, and Altus Air Force Bases. The assumed home base for maintenance of a military version of the 747-400F was Dover. For en route stops, the military airlift fleet used Dover, McGuire, Charleston, Rhein-Main, Torrejon, Lajes, and Cairo West. The CRAF used commercial airports. The routes used for each deployment stream were patterned after the Gulf War airlift experience and were reviewed with the Air Mobility Command at the time of the research. Since then, AMC and the Air Staff have been developing alternative policies for routing aircraft that include an emphasis on the use of recovery bases in theater for changing flight crews and for refueling aircraft. Thus, current Air Force plans differ from the routes used in RAND's scenario. They do not rely on using Lajes to refuel transports, and they use different policies for sending transports to AMC's bases in CONUS for maintenance. The differences in the route structure have the effect of requiring more stops per mission cycle than we used in our analysis. We believe that the Air Force's current plans for routes would lower our calculated utilization rates for all aircraft and would modestly reduce the differences in utilization rates between aircraft.

[33]The polar routes were constrained (Figure 4.13) to avoid flying over the former Soviet Union and Eastern Europe.

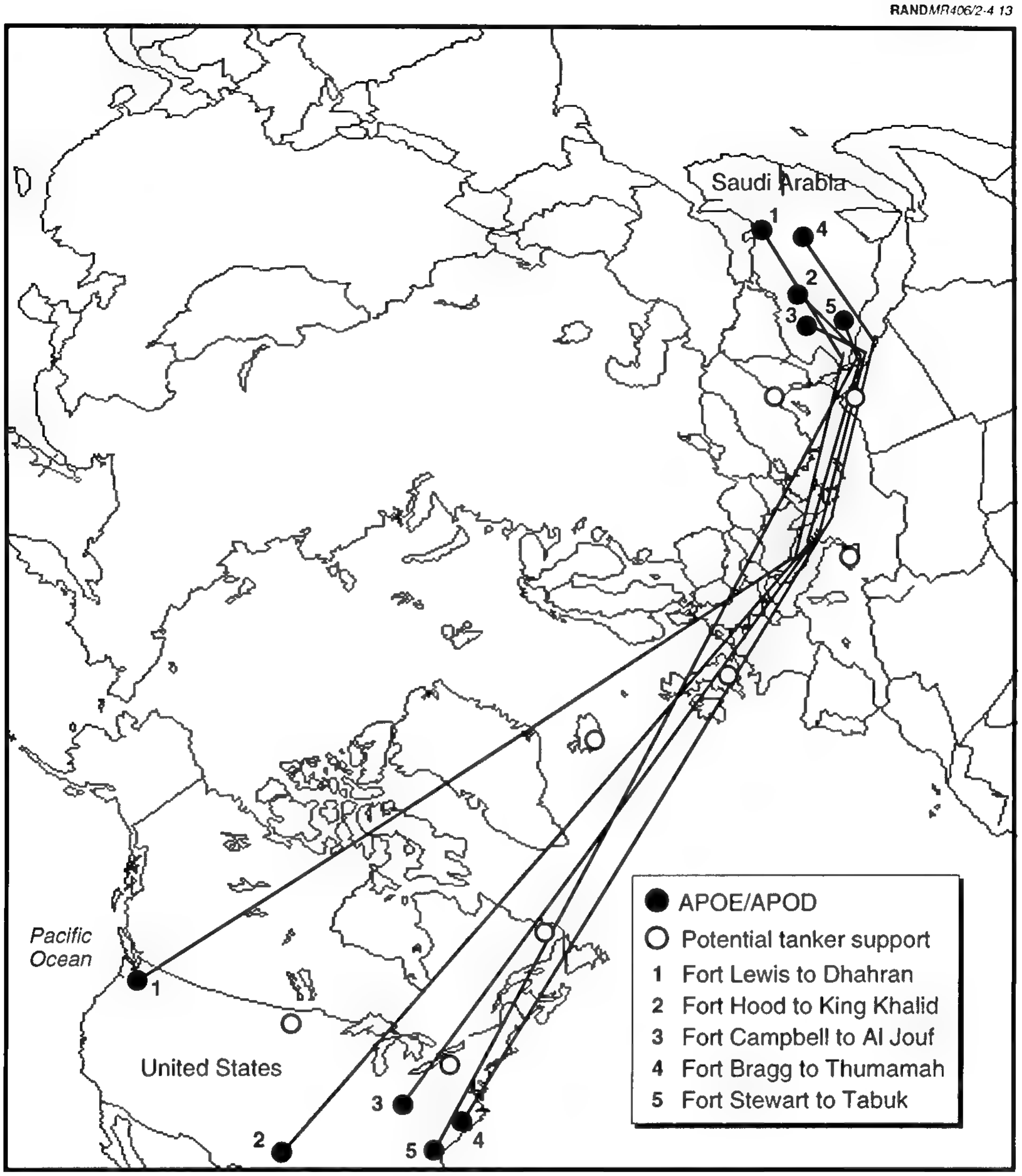

Figure 4.13—Deployment Mission Cycles for the Case of Polar Routes and Aerial Refueling

Each spreadsheet calculated airlift system performance parameters for the demands on theater resources (Figure 4.14), the elapsed mission cycle time, and the total flying time for that cycle.

Missions Were Manually Planned. For each spreadsheet, routes were manually planned (Step 1 in Figure 4.15). Distances were calculated for each leg of each mission, and block speeds were set according to the leg distance and whether an aerial-refueling event occurred during that leg. The spreadsheet then calculated airlift system performance parameters. For each mission cycle requiring aerial refueling,

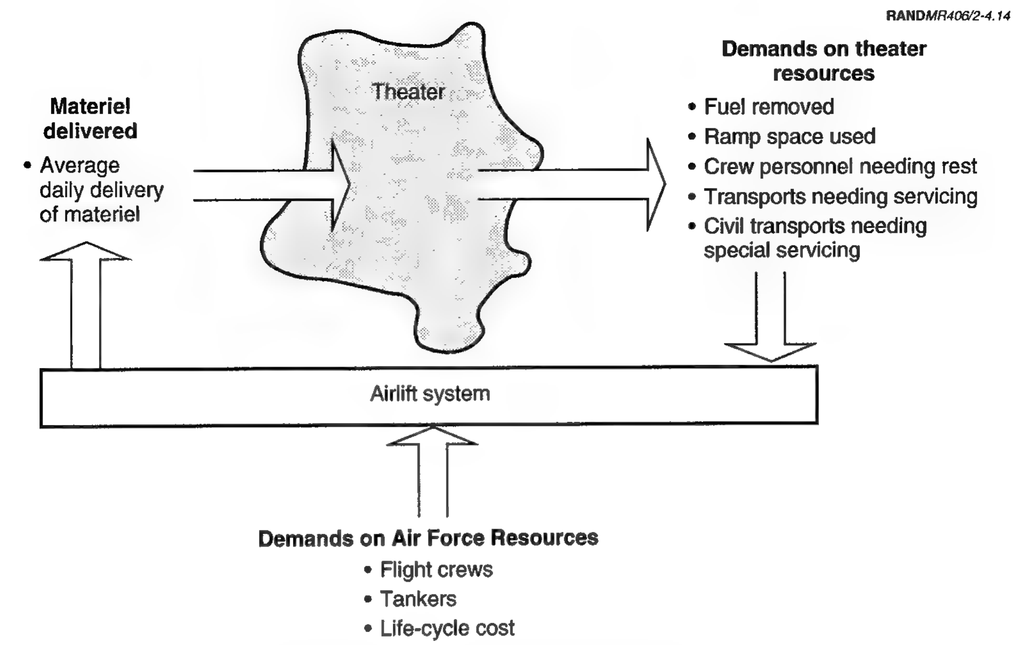

Figure 4.14—RAND's Mission-Cycle Analysis Spreadsheets Calculated Materiel Delivered and Demands on Resources

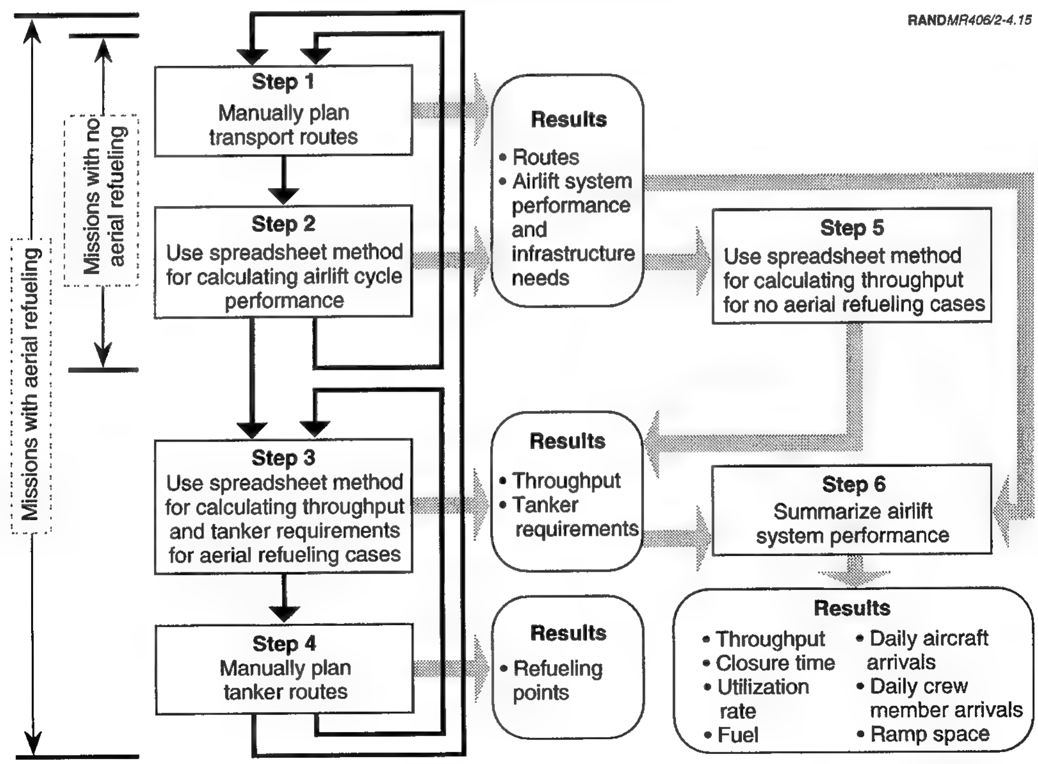

Figure 4.15—Process for Evaluating Airlift System Performance and Infrastructure Needs for Alternative Fleets of Transport Aircraft

tanker requirements were calculated (Steps 3 and 4), then Steps 1, 2, 3, and 4 were repeated until satisfactory locations were identified where aerial refueling events should start. Throughput in tons delivered daily by a set of transports was calculated (Steps 3 and 5) based upon the mission-cycle performance results, the number of transports assigned to the deployment streams, and the average payloads used in the mission-cycle analysis. Results were then summarized in Step 6 for alternative airlift fleets.

Average Payloads Were Set to Reflect Aircraft Range Performance and Gulf War Deck Loads. Average payloads were determined by considering each aircraft's payload-versus-range trade-off curve (Figure 4.16) and the cargo-deck sizes illustrated in Figure 4.17. Heights of cargo cabins and door dimensions were also taken into account. The payloads used in the mission-cycle analysis are shown in Figure 4.18.

Each of the payloads in Figure 4.18 is feasible for a 3500 nmi distance between bases and no head wind.[34] Moreover, each payload reflects the Air Force's assessment of the average density of cargo for deploying the Army's outsize or oversize equipment on the C-5 and C-141 (oversize only) over a 3500 nmi distance with no head wind (see U.S. Air Force, 1987). For the military-style transports, the average cargo density

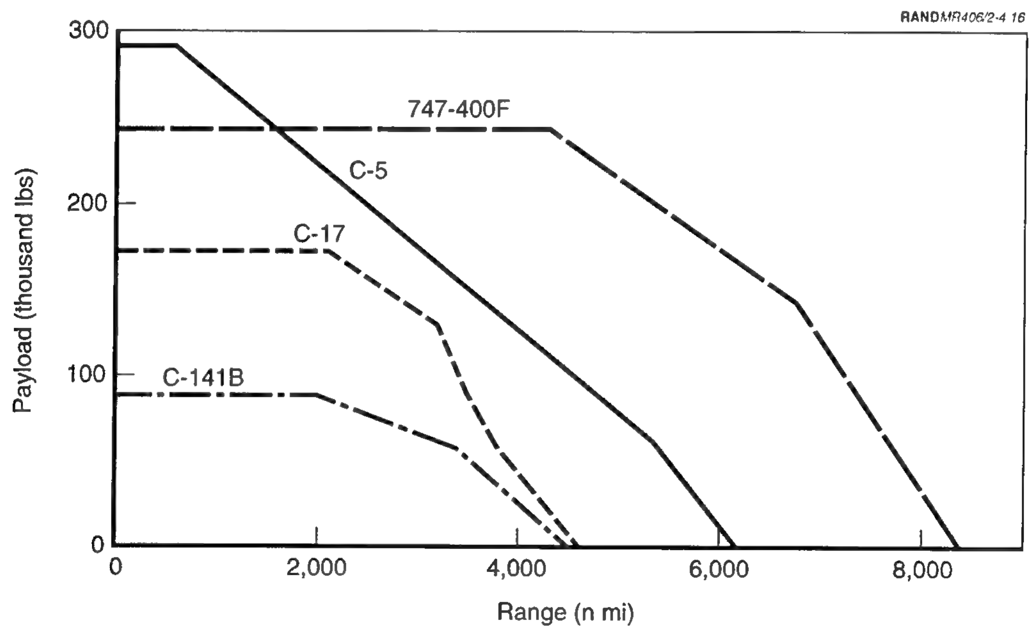

Figure 4.16—Payload as a Function of Range for Transport Aircraft

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[34]Since the completion of the research, the C-17's payloads have been reduced for distances of instance to this research. The payload in Figure 4.18 may be very close to being unfeasible for a distance of 3500 nmi (see Volume 3, Appendix B). Such an outcome could lower our estimate for the C-17's throughput.

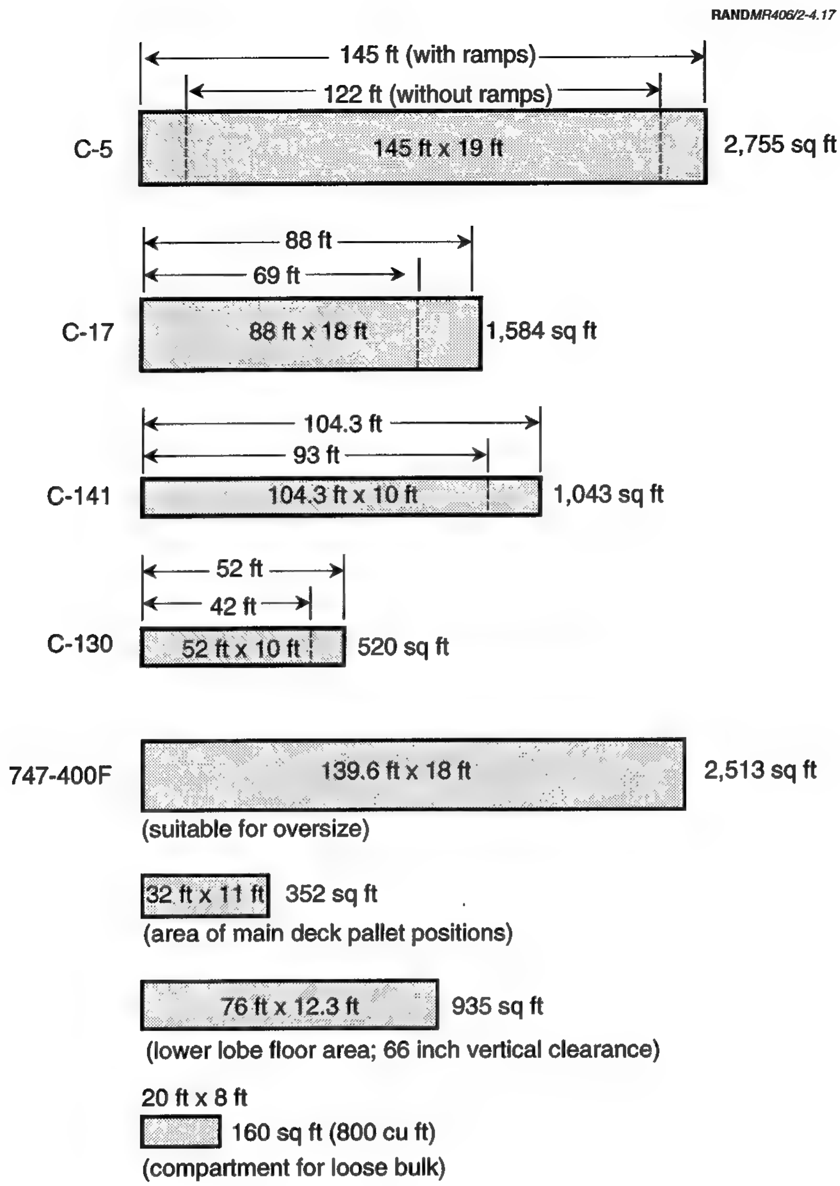

Figure 4.17—Cargo Floor Space for Transport Aircraft

is such that the average floor loading for each aircraft is 47 lbs of cargo per sq ft of floor area. By maintaining the same floor loading, we are assured that the same assumption is being used for the average density of the cargo.[35]

[35]Recent analyses by DoD for a critical leg length of 3,200 n mi show the C-17 with a 15 percent higher average deck load than that of the C-5 and the C-141. For the longer critical leg lengths applicable to a deployment to Southwest Asia, we would expect a smaller difference.

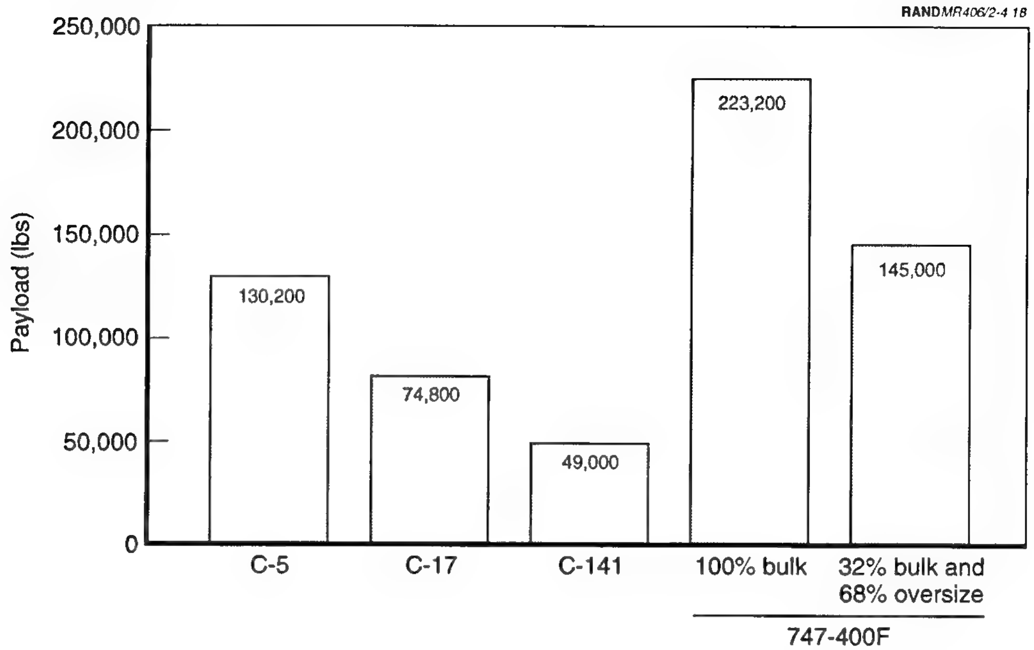

Figure 4.18—Average Payloads Used in the Mission-Cycle Analysis for the Southwest Asia Scenario

The payloads for the 747-400F reflect two conditions. In one, only bulk materiel is being carried; in the other, a mix of oversize and bulk is carried.

The average cargo density for bulk materiel is taken from Air Force planning factors. The payloads for the 747-400F are assumed to be the same as the planning factor payloads for a 747-200F flying a distance of 3500 nmi with no head wind.

Assuming that oversize materiel would be carried only on the main deck within the unobstructed rectangular area measuring 140 ft by 18 ft, we estimate that for the oversize mission, about 32 percent of the load would be bulk cargo stored in lower lobes and on pallets in the nose and tail areas of the main deck. With these assumptions, we deduce that the average deck load for the oversize materiel would be 39 lbs of cargo per sq ft of the deck area identified for carrying oversize cargo. This lower density is plausible in view of the fact that the 96 inch vertical clearance means that trucks and trailers cannot be loaded as high as they might when being carried by a C-141 or a C-5 (see Volume 3, Appendix B, for further discussion of payloads).[36]

[36]The Air Force has raised concerns about the payload we used for the 747-400F when carrying bulk cargo in view of the performance of the 747-200F during the Gulf War. Volume 3, Appendix B discusses why the Gulf War experience with a small number of 747-200Fs may not be a good indicator of the 747-400F's 7-percent larger capacity when operated in much larger quantities by the Air Force and when loads are prepared to exploit the capacity and range performance of the aircraft. On the other hand, the reader may want to consider the possibility that the payload for bulk cargo missions might be about 17 percent lower if the Gulf War is a good indicator and if commercial pallets and containers are not used. Such a reduction in payload would yield the same percentage reduction in fleet throughput for the 747-400F. If the Gulf War experience is used for the military-style transports as well, then their payloads should be reduced by about 5 percent in recognition of the lower cargo densities realized by the C-5. (C-141 densities were 20

SENSITIVITY ANALYSIS EXPLORED AERIAL REFUELING AND TESTED TOOLS

The purpose of the sensitivity analysis was to learn how transport and tanker aircraft might best be applied in major airlift operations. To do this, we researched the potential benefits of using aerial refueling to raise the throughput provided by each type of transport aircraft. In this first application of the new analysis tools, we also had the opportunity to test the reasonableness of the results.

Aerial Refueling Can Increase Airlift

To explore the potential contribution of aerial refueling to improved utilization of transport aircraft, the research explored a wide variety of potential combinations of tankers (KC-135R and KC-10), transports (C-5, C-141, C-17, and the military version of the 747-400), routes (polar and great circle), and methods for refueling missions (rendezvous, buddy, and rendezvous in the vicinity of the tanker's deployed operating base).

Deployment Scenario Was Analyzed With and Without Aerial Refueling. For the "no aerial refueling" scenario, we planned great-circle routes between airfields and assumed the availability of en route airfields at Dover, McGuire, Lajes, Torrejon, Rhein-Main, and Cairo. For the first aerial refueling scenario (the "Great-Circle Scenario"), we based tankers at the en route stops and planned refueling to occur in the vicinity of the en route stop. For the second aerial refueling scenario, we planned polar routes (the "Polar Scenario") for the missions, as illustrated in Figure 4.13. Although the polar routing yielded the minimum round-trip times ("mission-cycle times"), it placed greater demands on the tanker resources, because the tankers had to fly longer distances to rendezvous with the transports. Because the Great-Circle Scenario provided the least-cost application of the tanker resources, it was used for the analyses addressed in the remainder of this chapter. For missed refuelings, the transports would land and refuel at the tanker base. This approach seemed to offer the best method for efficient use of the tankers while addressing the problem of missed aerial refuelings.

To assess the tanker requirements for each type of transport and each type of mission, it was necessary to model the mission performance of the alternative tankers. For each combination of tanker type, transport type, and airlift mission, supporting tanker missions were defined. Tanker performance was modeled in terms of the amount of fuel that could be transferred to a transport. This offload capability was sensitive to the tanker's takeoff conditions (temperature and runway altitude, length, and wetness), distance the tanker would fly to meet the transport, and fuel transfer time. The fuel needs of the transports were modeled by selecting fuel transfer points that minimized the number of aerial refuelings, subject to constraints that required

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percent lower than we used in our analysis.) Furthermore, if the Air Force cannot make good use of the additional capacity and range of the 747-400F, as do commercial air carriers, then it may be more cost-effective for the DoD to buy and refurbish the older models.

sufficient fuel onboard the transport to handle the possibility of an aborted aerial refueling, which would require the transport to divert to an airfield.

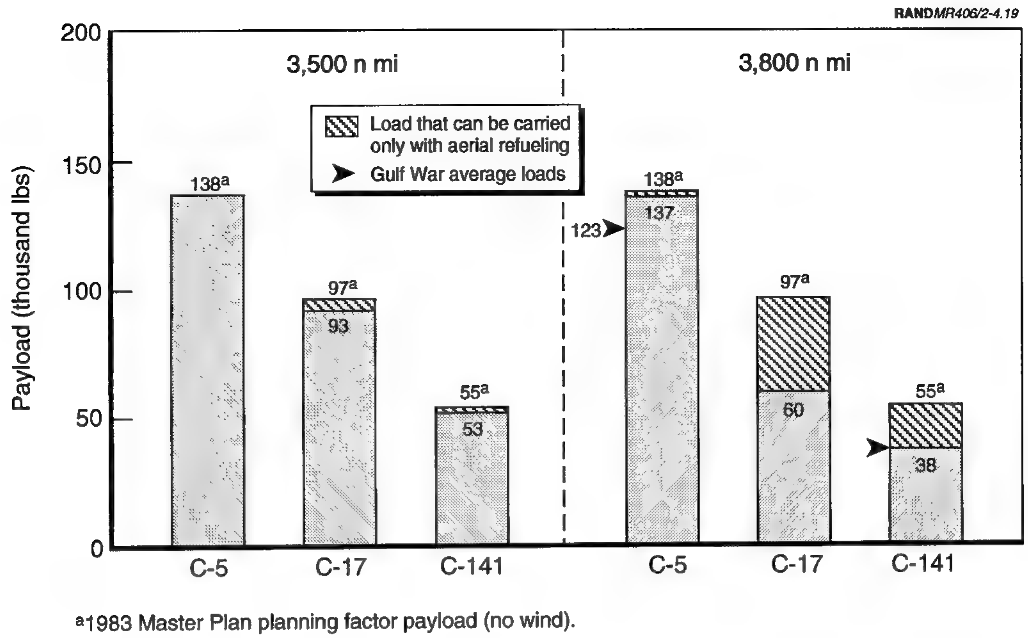
Assumptions Were Made to Find the Maximum Potential Benefit of Aerial Refueling. To understand the maximum potential benefit and the conditions that would have to exist to realize that benefit, the analysis was based upon the following assumptions that favored using aerial refueling to raise airlift production:

- **Basing of tankers.** Tankers would be based at convenient locations to minimize the adverse impact on the routing of the transports and maximize the effectiveness of the tankers.
- **Accommodations for crew rest.** Air crews would be provided accommodations for crew rest at the APOE and the APOD. Otherwise, the transports would have to make additional time-consuming stops for changing crews. Such stops would lengthen cycle times and reduce the productivity gain that aerial refueling offers.
- **Crew ratios.** The number of air crews per transport aircraft would be increased as necessary to handle the longer missions and the higher utilization rates that would result from using aerial refueling.
- **No en route stops.** No en route stops would be required, because there would be sufficient tanker resources, air bases to support tanker operations, accommodations for crew rest, and air crews.

Limitations on the Range Performance of the C-17 and the C-141 Make Them Strong Candidates for Aerial Refueling. From the vantage point of the range-performance capabilities of individual aircraft, the C-17 and the C-141 have the greatest potential to benefit from aerial refueling for carrying typical deployment loads on the types of mission routes that have been used by military-style transports. Under the assumption that there were no headwinds or tailwinds, the planning-factor payload capabilities of the C-17 and the C-141 can only be achieved for critical leg lengths greater than 3,500 n mi with the assistance of aerial refueling (Figure 4.19). The C-5 similarly benefits from aerial refueling when critical-leg lengths exceed 3,800 n mi. As noted earlier, nearly half of the busiest mission routes between CONUS and Europe during the Gulf War involved critical leg lengths of at least 3,400 n mi.

Westbound Deployments Need Aerial Refueling More Than Eastbound Deployments. A Southwest Asia deployment has the advantage of being less influenced by headwinds than a westbound deployment, say, to Southeast Asia. The headwind difference can easily amount to 70 n mi per hour. To appreciate the consequences this has on range and payload, such a headwind of 70 n mi per hour reduces the distances in Figure 4.16 by about 600 n mi when the distance between bases is about 3,500 n mi. Thus, for example, a C-17 or a C-141 flying into such a headwind of 70 n mi per hour needs the assistance of aerial refueling to carry a planning factor payload more than 2,900 n mi between air bases.

A further consideration on westbound deployments is the distance between bases that might be used for en route stops. Figure 4.20 shows the route segments that exceed 3,500 n mi (ground distance) for the AMC's routine route system. Several of



a1983 Master Plan planning factor payload (no wind).

Figure 4.19—Military Transports Need Aerial Refueling to Allow Payloads to Reach Planning-Factor Levels Once Distances Go Beyond About 3,500 n mi

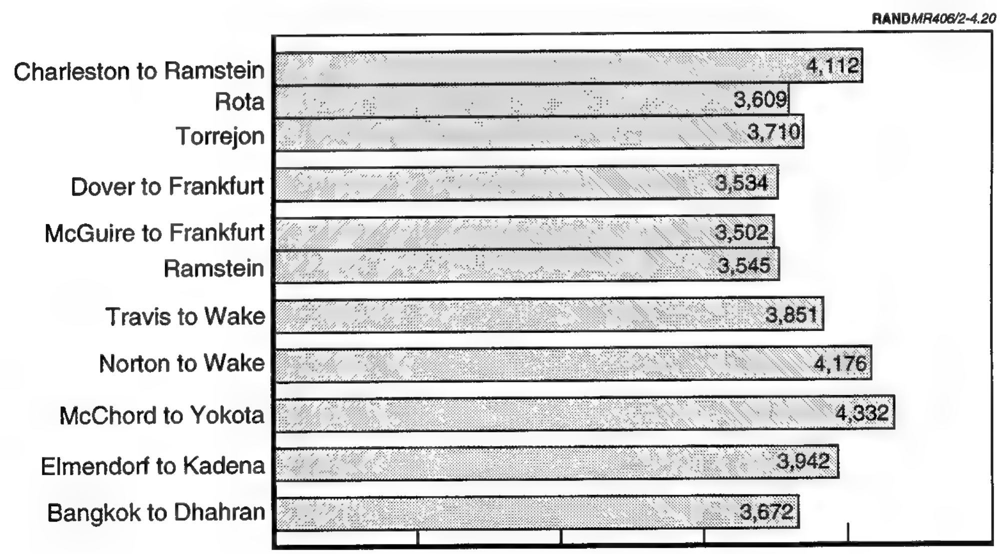


Figure 4.20—Route Segments That Are Greater Than 3,500 n mi

these long-distance route segments are candidates for use in westbound deployments. The combination of such long distances and headwinds makes westbound deployments far more in need of aerial refueling support.

Aerial Refueling Decreases Mission-Cycle Time. Because aerial refueling eliminated en route stops in our mission-cycle analysis, mission-cycle times for all aircraft show beneficial reductions (Figure 4.21). The average mission-cycle time for the C-5 is higher than that for the other aircraft because of its greater maintenance needs. The reduction in mission-cycle time is greatest for the C-5, because aerial refueling reduces the wear on systems used mainly during takeoff and landing. It is these systems that account for much of the C-5's greater maintenance needs. The 747 had the lowest average mission-cycle times (Figure 4.21) because of its lower need for maintenance and its faster block speeds (Figure 4.22). The higher block speeds reflect the 747's higher cruising speeds and its greater range capability, which reduce its need to slow down for refueling.[37]

The 747 depicted in Figure 4.21 would be a military version of the 747-400F. For the most effective military use, the 747-400F should be modified to include (1) a wide side door for loading most oversize cargo, (2) a strong floor, (3) emergency exit doors and removable seating pallets for rapid conversion to a passenger configuration, (4) aerial refueling (for increased flexibility), and (5) military radio and navigation equipment.[38] To cover the costs of these modifications, we assumed an additional $20 million for each aircraft. Such modified 747-400Fs are assumed throughout this analysis.

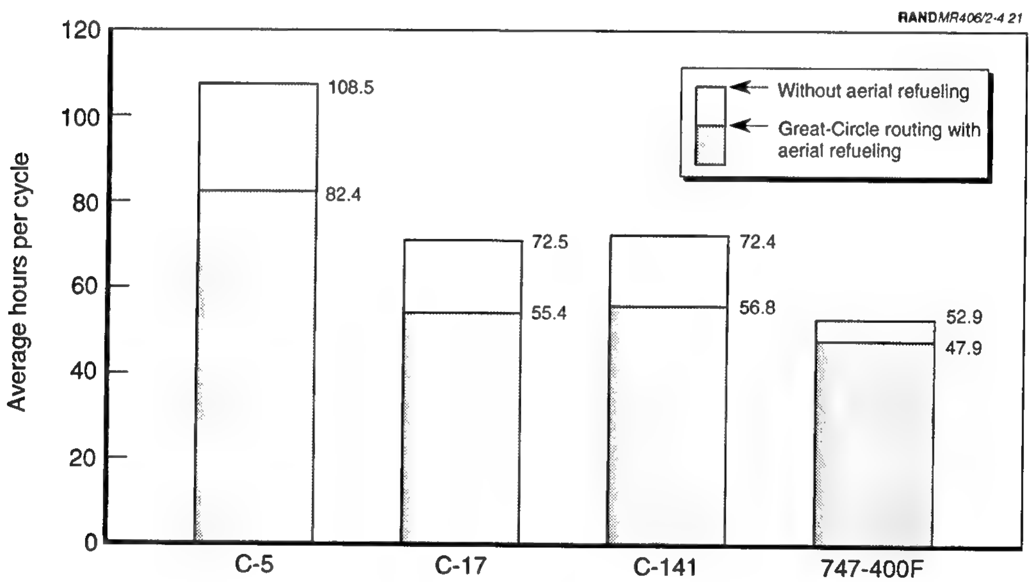


Figure 4.21—Average Cycle Time for the Deployment Mission Cycles for the Southwest Asia Scenario

[37]At the time of publication, the Air Staff's planning factor for 747-400F block speed is 450 kts (see Volume 3, Appendix B).

[38]Although we assumed that the engines on the 747-400F would be calibrated to use JP-4, as are the engines on the military-style transports, this matter may warrant further consideration in view of the greater availability of commercial fuel (Jet A).

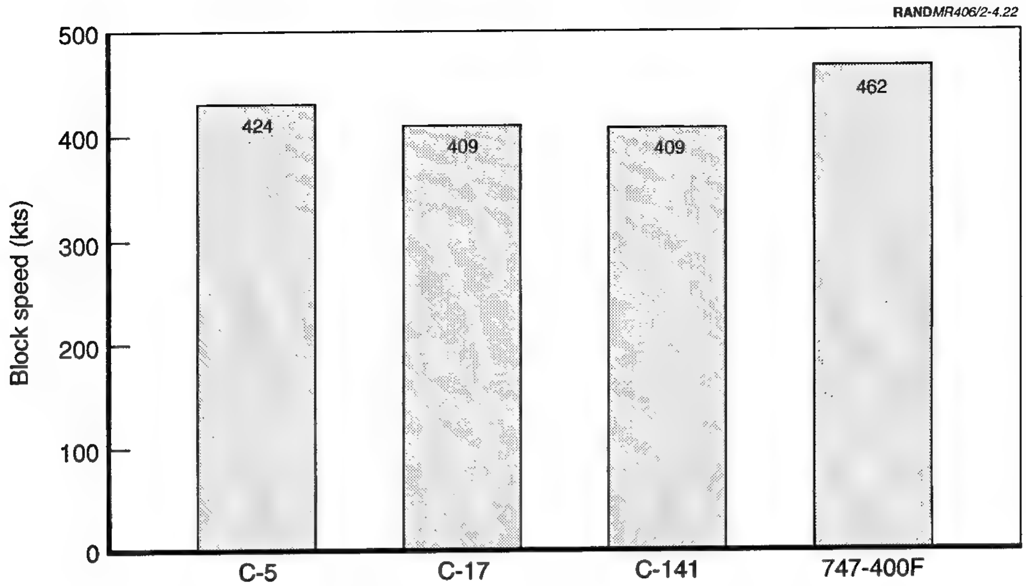


Figure 4.22—Average Block Speeds for the Deployment Mission Cycles for the Southwest Asia Scenario

Even though aerial refueling only slightly increased throughput for the scenario we used, aerial refueling is a relatively inexpensive modification that frees the aircraft from dependency on en route bases for refueling. Thus, it seems to be a wise hedge against the uncertain availability of en route bases.

Low Utilization Rates of the C-5 Make It a Strong Candidate for Aerial Refueling. Two approaches were used to estimate utilization rates (Figure 4.23). Both approaches showed that the C-5 had the lowest utilization rates for our Southwest Asia scenario, as it did during the Gulf War airlift (Figure 4.6). Because aerial refueling offers the C-5 the opportunity to reduce wear on high-maintenance systems, as well as eliminating the need for en route stops, the C-5 appears to be a prime candidate for benefiting from aerial refueling.

The first method for estimating utilization rates uses the Air Mobility Command's 1992 planning factors for loading, unloading, and refueling.[39] It also accounts for delays due to weather and operational causes by drawing on Gulf War airlift experience. Large aircraft (C-5, CRAF 747-200, and 747-400F) were assigned average delays of 1.1 hours per stop, and small aircraft (C-141) were assigned average delays of 0.6 hours per stop. The C-17, midway between the C-141 and the C-5 in size, was assigned an average delay of 0.8 hours per stop.

[39]If the Air Staff's ground time factors are used and if the C-17 and the 747-400F are required to make the same number of stops at CONUS bases for refueling, our estimated utilization rates would change: The estimate for the C-17 would increase from 12.2 to 12.8 hrs per day and the estimate for the 747-400F would decrease from 14.7 to 14 hrs per day.

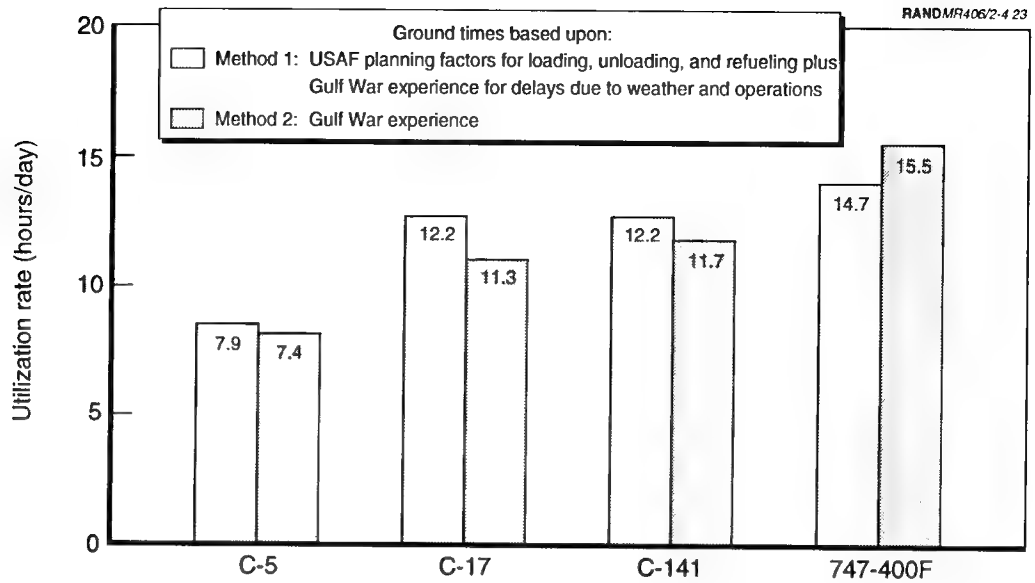


Figure 4.23—Average Utilization Rate for the Deployment Mission Cycles for the Southwest Asia Scenario

The second method used Gulf War experience for loading, unloading, refueling, and delays due to weather and operational causes. Generally the military transports have higher estimated utilization rates with the first method, whereas the 747-400F has a higher estimated utilization rate with the second method. For the purposes of the throughput calculations we gave the benefit of the doubt to the military transports by using the first method to estimate the utilization rates for both military and civil transports. In assessing national airlift capability, however, we used the second method because it seems to be more realistic.

Military-Style Transports Have Comparable Opportunities to Benefit from Aerial Refueling. The mission-cycle analysis showed, however, that the throughput for each of the military-style transports had a comparable opportunity to benefit from aerial refueling (Figures 4.24 and 4.25). In each case, aerial refueling yielded almost a one-third increase in the amount of cargo that the military-style transports could deploy to Southwest Asia. The 747 aircraft does not benefit nearly as much from aerial refueling because it has much less need for refueling than do the military-style transports.

In contrast to RAND's result, AMC analyses have shown a throughput improvement of only up to 6 percent, depending on the scenario. Much of the difference between the RAND and AMC estimates comes from two sources. First, contrary to current AMC practice, our analysis assumed that flight crews could be provided facilities for rest between missions at both APODs and APOEs to avoid additional stops to change crews. Second, our analysis assumed that the reduction in landings and takeoffs would reduce the need for maintenance and thereby reduce the number of stops re-

RANDMR406/2-4.24

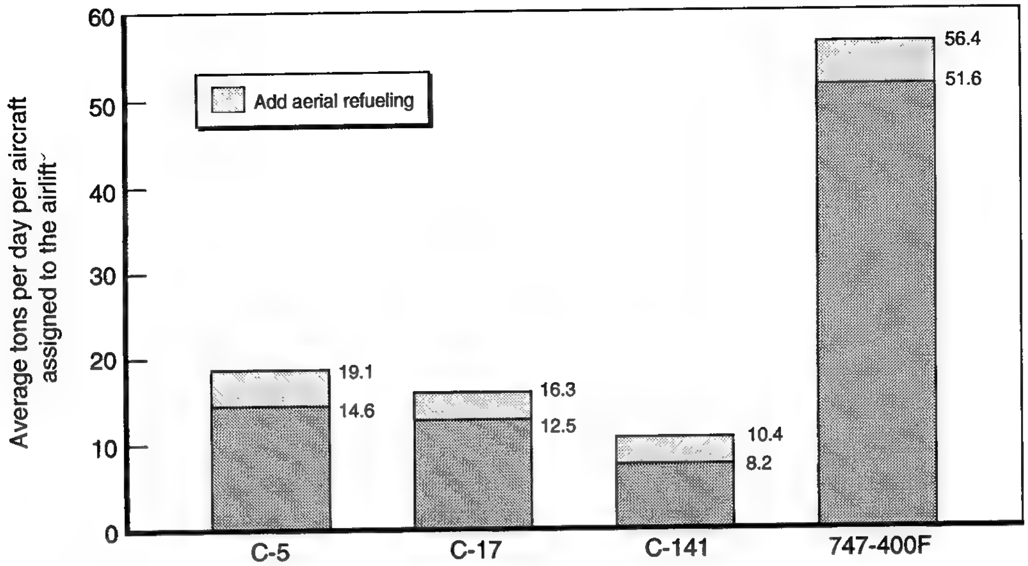


Figure 4.24—Influence of Aerial Refueling on the Average Daily Throughput for the Southwest Asia Scenario for the Case of Great-Circle Routing

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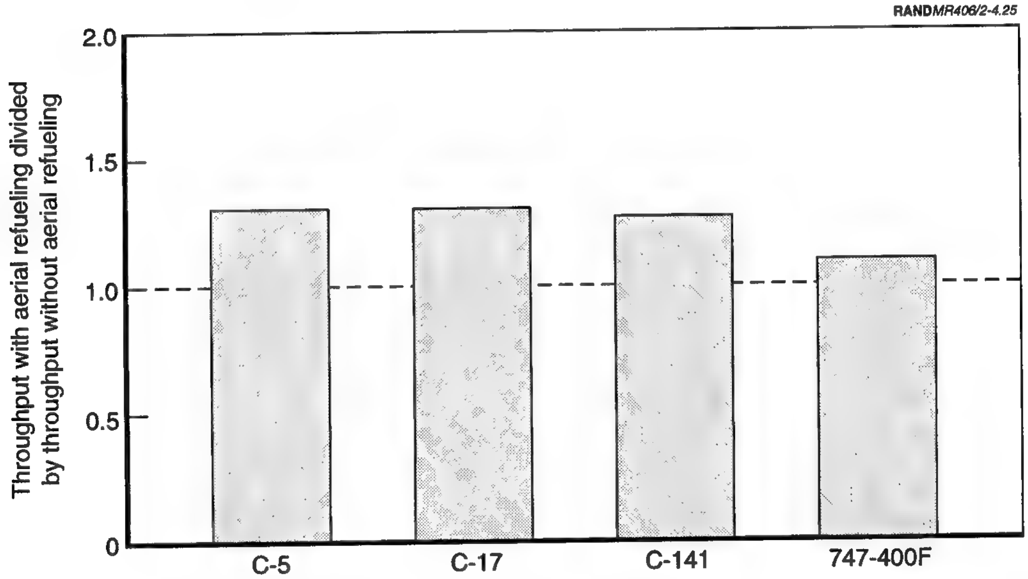

Figure 4.25—Aerial Refueling Increases Throughput for Southwest Asia Deployment

quired at a home base. Both RAND and AMC assumed that bases would be conveniently available to support tanker operations.

Although our analysis showed that deviations from these assumptions quickly erode the benefits of aerial refueling, the analysis also showed a significant benefit to minimizing the number of stops and keeping transport aircraft airborne for as long

as possible. Thus, to derive the most benefit from aerial refueling, the Air Force may find it beneficial to consider new policies calling for (1) stopping at a home base only when needed for maintenance and (2) changing crews only when aircraft must land to load, unload, or receive essential maintenance.

Comparison of Utilization Rates Tested Mission-Cycle Analysis Tools

We used aircraft utilization rates to test the mission-cycle analysis tools by comparing our analysis results with the experience of the Gulf War airlift. Care must be exercised, however, when comparing the utilization rates in Figures 4.6 and 4.23. Figure 4.6 presents worldwide rates for entire fleets, whereas Figure 4.23 only addresses those aircraft involved in the Southwest Asia scenario analyzed in this chapter. Figure 4.6 shows the C-5 achieving a worldwide utilization rate of 5.5 hours per day during the second surge of the Gulf War—much lower than our mission-cycle analysis result of 7.4, which is based upon ground-time factors derived from the Gulf War experience. Why was the C-5's worldwide utilization during the Gulf War's second surge 26 percent lower than what our mission-cycle analysis found to be a reasonable expectation for a Southwest Asia scenario? We believe it reflects scheduling inefficiencies and perhaps lower utilization rates for the aircraft not assigned to the Gulf War airlift.

The C-141 achieved a worldwide utilization rate of 7.1 hours per day during the Gulf War's second surge (Figure 4.6), whereas our mission-cycle analysis yielded an 11.7-hour-per-day utilization rate. Why was the C-141's worldwide utilization during the Gulf War's second surge 39 percent lower than what our mission-cycle analysis found to be a reasonable expectation for a Southwest Asia scenario? In pursuing this question, we found an interesting set of signs regarding the use of the C-141 in the Gulf War airlift.

There Appears to Have Been an Excess of C-141 Airlift Capacity During the Gulf War

In trying to resolve the difference between our analytical outcome and the Gulf War airlift performance of the C-141, we found several signs suggesting that the supply of C-141 airlift capacity exceeded the demands of the Gulf War airlift:

- Civil-style, wide-body transports were more desirable than the C-141 for carrying bulk cargo:
  - They used civil airfields en route, thereby relieving congestion at the main en route military airfields (Torrejon and Rhein-Main).
  - They did not require the use of the military's cargo pallet (463L) that was in scarce supply due to problems of returning the pallets from deployed units.[40]

[40] Lund, Berg, and Replogle, 1993, report that many deployed units used the pallets for their local needs rather than returning them for use in further airlift missions. The military-style transports have a loading system that requires the use of the military's special pallets.

- They were easier to unload, because the 747 freighters had powered rollers built into the floor that allow a single loadmaster to move containers and pallets.[41]
- They delivered more cargo per unit of ramp space at the destination airfield (daily average of 10 lbs of cargo per sq ft of ramp space versus 3.5 for the C-141).
- They delivered more cargo per pound of fuel taken from theater supplies (1.5 lbs of cargo per pound of fuel versus 0.5 for the C-141).
- They used commercial fuel (Jet A) rather than the military fuel (JP-4), which was also in high demand for use by the Air Force's other military aircraft.

- In the lull between surges, CRAF Stage I cargo remained activated even though the C-141's worldwide utilization rates fell to 29 percent (3.4 hours per day[42]) of our assessed capability.
- During the second surge of the Gulf War airlift, although the availability of the C-141 was much higher than that of the C-5 (85 percent versus 68 percent), it had a lower percentage application of what our mission-cycle analysis methodology assessed to have been its airlift capability (63 percent versus 74 percent).
- One-fourth of the C-141 reserve units were not activated before the air-war phase of the Gulf War airlift.[43]
- There are reports that the civil-style transports were given priority over military transports for loading and unloading.[44]

It appears that, while the supply of civil-style cargo transports was insufficient to meet the demands of the Gulf War's second surge for airlift, the supply of C-141 capability seems to have exceeded the demands of the Gulf War airlift, at least in terms of how the airlift was executed.

ANALYSIS OF MILITARY AIRLIFT OPTIONS YIELDS ESTIMATE FOR RIGHT MIX

The course the DoD was pursuing during FY 1992 would alter the level and composition of the airlift fleet, as illustrated in Figure 4.26. The amount of outsize capacity would move from about one-third to almost two-thirds of the total airlift capability for cargo.[45] Given the high cost of outsize capabilities and the modest level of the demand for outsize airlift during the Gulf War, the DoD is faced with major decisions

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[41]The military-style transports, optimized for moving rolling stock, lack a powered roller system.

[42]The C-5 utilization rate during this period was 4.2 (see Figure 4.6).

[43]Seven C-141 units were activated between August 25 and September 10. Four were activated after the air war started (2 on January 24 and 2 on February 19). All C-5 units were activated.

[44]This observation came from the Staff, Headquarters MAC, during April 1992, in explaining why the civil transports had shorter ground times than the military transports (see Figure 4.7).

[45]The C-17 can carry almost all outsize materiel.

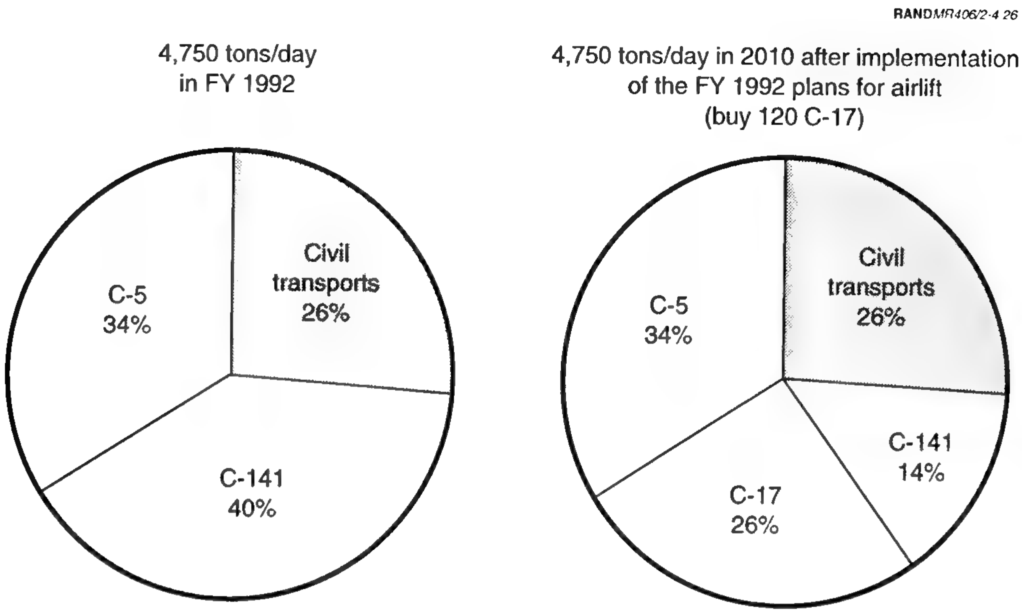

Figure 4.26—Estimated Capacity of the Total Airlift Fleet to Deliver Materiel to Southwest Asia After Stage II Activation of the FY 1992 CRAF

regarding the level and composition of the military airlift fleet. To contribute to that decisionmaking process, this research undertook an analysis of alternative fleets for military airlift.

Analysis Was Structured to Estimate the Right Mix for the Military Airlift Fleet

Using a Southwest Asia scenario, we structured the analysis to estimate the right mix of military and civil airlift.

Air Force's 1992 Plan for Retaining Airlift Assets Was Used as the Base Case. The base case includes the 1992 inventory of 109 PAA[46] C-5 aircraft plus 80 PAA C-141 aircraft that the Air Force had been planning to retain past the year 2010. The base case also included the activation of a CRAF capability equivalent to that activated during the Gulf War: Stage I for passenger aircraft (18 747-equivalent aircraft) and Stage II for cargo aircraft (28 747-200 freighter equivalent aircraft).[47]

Because the objective for the research was to find the right mix of airlift for large-scale intertheather deployments, we assumed that intertheater and intratheater airlift can be analyzed separately, with the C-130 performing most intratheater airlift missions. This separation seems reasonable, because the time required to deploy a

[46]PAA are the aircraft assigned to operational units. The Air Force's total aircraft inventory (TAI) for the C-5 is 126.

[47]Based on 1992 definitions for Stages I and II.

large force is much longer than the time required to move that force by surface within a theater. Thus, the C-130 does not appear in this analysis of intertheater airlift options (see Volume 3, Appendix A, for further discussions).

Regarding the Air Force's plan to retain 80 PAA C-141 aircraft in the inventory, we accepted that plan as part of the base case because the C-141 is ideally suited to supporting the brigade airdrop mission, and there seems to be a reasonable prospect that about 94 of the current 260 aircraft might be selected for life-extension modifications. We view the C-141 favorably for the airdrop mission because it can drop up to 150 paratroops and often drops about 120,[48] whereas the C-17 can drop at most 102. The base case was held constant throughout the analysis. The analysis explored different options for adding aircraft to the base case.

Options for Enhancing the Base Case Focused on Trading C-17s for Lower Costs. Many possibilities were examined for adjusting to a smaller C-17 fleet. Concepts that were considered and rejected included increasing the number of flight crews and the addition of various civil-style transports smaller than the 747.[49]

- Because of limitations on aircraft utilization, increasing flight crews only proved worthwhile in certain instances when aerial refueling resulted in such long missions that the normal size of the flight crew had to be increased.
- Civil-style transports smaller than the 747 also proved uninteresting, because they could not compete with the economic advantage and global reach of the 747-400F in moving very large quantities of bulk and oversize materiel over very long distances. Moreover, they could not match the 747's ability to carry much of the oversize materiel.

The smaller aircraft were attractive in that there would be more aircraft in the inventory, albeit with less total capability, assuming equal-cost fleets. The flexibility of possessing more smaller aircraft seemed to come at an economic cost that would be unreasonable, given an objective of trading C-17s for lower costs. Moreover, the shorter range of the smaller aircraft seemed less suited to the Air Force's mission of global reach.

Five options were selected to represent a spectrum of possibilities for reducing the C-17 production. The five options were initially sized to provide comparable order-of-magnitude increases in airlift capacity, as measured in terms of total tonnage delivered daily in the Southwest Asia scenario. As the analysis progressed, some options ended up providing less capacity than had initially been estimated, while others provided more.

[48]Members of our research team included several of RAND's U.S. Army fellows. The fellow with airborne and air drop experience researched the 82nd Airborne Division's practices and experience in air drops. The consensus he found was that the Army usually drops around 124 paratroopers from one C-141. On the other hand, the Air Staff reports that the drop requirement is 102 paratroopers per airplane.

[49]The C-17's prime contractor has proposed a change that would add fittings to the cargo floor, at some increased weight, that would allow for an alternative seating arrangement that could accommodate 150 paratroopers. The reasons for the Air Force lack of action on this change are unclear.

The options were structured to explore three levels of investment in the C-17. Option A includes the full fleet as planned by the Air Force in 1992. Options B and C examine C-17 fleets half that size, and Options D and E consider situations where there are no C-17s.

- **Option A** was designed to represent the Air Force's FY 1992 plan, which included the replacement of all but 80 PAA C-141 transports with 120 C-17 transports (102 PAA). Thus, adding Option A to the base case reflected the Air Force's baseline program at the time of our work.

The remaining four options explore different approaches that the Air Force might pursue to adjust to a smaller C-17 fleet. Option B makes the adjustment while rejecting the idea that a civil-style transport should be added to the military airlift fleet.

- **Option B** increases the size of the C-5 fleet to compensate for a smaller C-17 fleet. This option reduces the C-17 procurement to 60 airplanes (51 PAA) and adds 60 additional C-5s (51 PAA).[50] Table 4.2 identifies the C-5 as a C-5C model; as such, it should be an improved version of the C-5B model, with emphasis on improved reliability and maintainability. In all other respects, it would be essentially the same as the C-5B, although the Air Force might want to consider the possibility of going to an upgraded engine to improve takeoff and landing performance, and possibly fuel consumption.

The three remaining options accept the idea that a civil-style transport should be added to the military airlift fleet.[51] Options C and D, however, split the investment between military- and civil-style transports.

Table 4.2

Life-Cycle Cost for the Options

Option	Buy C-17	Buy C-5C	DoD Buys 747-400	Use Existing KC-10	25-Year Life-Cycle Cost (1992 $B)
A	102 (120)[a]				39
B	51 (60)	51 (60)			43
C	51 (60)		24 (28)		30
D	—		24 (28)	57 (59)[b]	36
E	—		36 (42)		15

[a]Numbers indicate PAA (TAI).

[b]Assign existing KC-10 equivalents to refuel the C-5 and add 2.4 crews per C-5.

[50]Assumed configuration and costs for the C-5s are similar to the C-5B.

[51]The airlift job for a very large crisis can be thought of as a need to move a mix of cargo and personnel from one mix of bases to another mix of bases by using a mix of transports and any available tankers that might be borrowed to boost airlift capacity. The problem then becomes one of matching transports with loads, bases, and tankers. Some transports can take off from bases with short runways and land at bases with short runways. Other transports need bases with long runways. Such an approach to airlift, however, increases the pressure on command, control, and communication to continuously match airlift and tanker resources (including infrastructure) with needs. Upgrading command and control, as well as communication and computer systems, is crucial to getting the most from airlift and tanker resources. The introduction of a civil-style transport to the military airlift fleet further increases the need for improved C^4 to match aircraft appropriately to the loads they can best carry.

- **Option C** was designed to compensate for a smaller C-17 fleet by purchasing a militarized version of the 747-400 freighter. This option assumes 60 C-17s (51 PAA) and 28 747-400 transports (24 PAA).
- **Option D** was designed to explore how tankers might be used to help adjust to the possibility of there being no (or very few) C-17s. Option D explores the possibility of increasing the throughput of the C-5 fleet by using aerial refueling. The KC-10 fleet is used entirely in an aerial-refueling mode to increase the outsize delivery capacity of the C-5 fleet by reducing the ground times for C-5s.[52] The addition of aerial refueling increased the daily flying rates for the C-5 to the extent that the number of flight crews had to be increased from 3.0 to 5.4 per PAA. This increased flying contributed to the cost of this option. In addition, Option D included the procurement of 28 747-400 transports (24 PAA).
- **Option E** was designed to explore the possibility that outsize capability may be adequate in the form of the current C-5 fleet and that the Air Force most needs to focus on bolstering its capability to move bulk, oversize, and passengers efficiently instead. Of the options, Option E explores the largest shift from military-to civil-style transports. The option has no C-17s but includes 42 747-400s (36 PAA).

Initial Allocation of Transports Was Simplified, and Reallocation Feasibility Was Tested. To simplify the initial analysis, we allocated the transport aircraft supporting the deployment equally across the five streams. Later, when loading data for the units became available, we analyzed the composition of the loads to be moved and verified that transports could be reallocated to satisfy the load requirements for each deploying unit. To simplify scheduling, command, and control in the analysis, aircraft, once assigned to a deployment stream, remained with that stream throughout the deployment. This approach avoids having aircraft waiting for mission assignments.

Cost Assessments Found Major Differences in the Options

Life-Cycle Costs Are Lowest for Option E and Highest for Option B. The 25-year life-cycle cost information depicted in Table 4.2 considers only cost remaining, starting with funds authorized in the FY 1993 budget.[53] Thus, all funds authorized for the C-17 program through FY 1992 are ignored and treated as sunk costs, even though it typically takes about three years to use funds once after they have been authorized. For example, the funds authorized in the FY 1992 budget will actually be used during FYs 1992, 1993, and 1994 as the contractor is paid for completed work. The life-cycle costs include acquisition, operations, and support.[54]

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[52]The KC-10 tanker fleet is only used in the instance of Option D.

[53]The 1992 present values for the 25-year costs in Table 4.2 for Options A through E are (in billions of 1992 dollars), for a 5-percent discount rate: 26, 29, 20, 21, and 9; for a 10-percent discount rate: 19, 21, 14, 13, and 6.

[54]Because there are significant uncertainties about future cost growth for the acquisition of the C-17 (beyond the FY 1991 projections), the C-17 portion of the cost estimates for Options A, B, and C may be low by as much as 15 percent. Also, the actual operations and support costs may be above or below esti-

By not considering the cost of procuring the KC-10 fleet (another sunk cost), we are implicitly assuming the Air Force has ample tankers, which may not be the case. Procuring additional tankers to support Option D would add about $8 billion to the cost of this option.

Regarding the refueling of the C-5 fleet called for in Option D, the Air Force's then-current crew ratio of 3.0 flight crews per PAA was insufficient to support the longer missions and the increased amount of flying that the C-5s could accomplish with the support of aerial refueling.[55] We found it necessary to increase the crew ratio to 5.4 (Figure 4.27). The life-cycle costs in Table 4.2 reflect the cost of that higher crew ratio.

Ramp Space Needs Are Least for Option A and Most for Option B. To illustrate the different demands each of the options places on ramp space in theater, Table 4.3 illustrates the average daily amount of destination ramp space required to support the

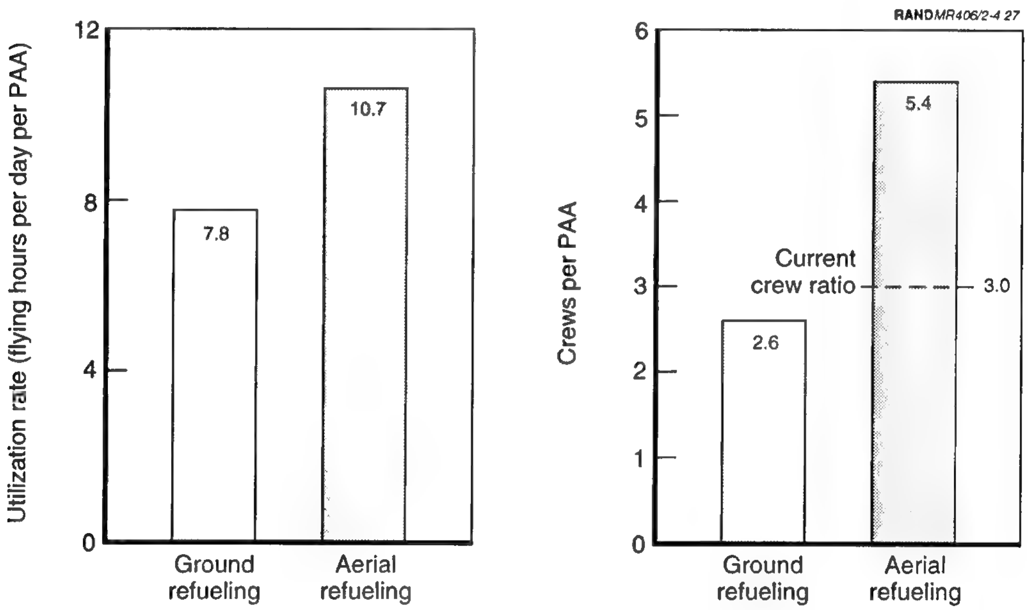

Figure 4.27—Aerial Refueling Fully Exploited with Increased Crew Ratio for the C-5

mates, depending upon the C-17's actual outcomes for reliability and maintainability. Moreover, the crew ratio might be reduced from 5 to 4 crews if our assessment of utilization rates is correct. Although that would reduce the cost for Option A by about 10 percent, other aspects of our estimates for operating and support costs have proved to underestimate these costs by a comparable amount. The cost estimates for Options D and E are on firmer ground (errors probably less than 15 percent), because there is more relevant acquisition and operational experience underlying the estimates. There is an issue, however, about the number of 747-400F aircraft procured for backup purposes that could reduce costs by about 5 percent for Option E (see Volume 3, Appendix D). We provided for five crews for each 747-400F. The acquisition portion of Option B pertaining to the C-5 is likewise on firmer ground because the production line has already been restarted once and the C-5B's operational experience underlies the estimate for the operations and support cost. On the other hand, the estimate for Option B may overstate the C-5's operations and support cost, because a C-5C would presumably have better R&M characteristics than are reflected in the average experience of the C-5B fleet.

[55]For the other aircraft, the Air Force's then-current crew ratio for the C-141 was adequate, as was the Air Force's plan for the C-17 and RAND's assumption for the 747-400.

Table 4.3

Ramp Space Required for Each Enhancement Option, Including the Base Case

Option	Military Aircraft (PAA)				Ramp Space (million sq ft/day)[a]
	C-17	C-5C	747-400	KC-10	
A	102	0	0	0	2.34
B	51	51	0	0	2.61
C	51	0	24	0	2.49
D	0	0	24	57	2.60
E	0	0	36	0	2.48

[a]Includes base-case ramp space of 1.97 million sq ft/day.

airlift operation, including the aircraft in the base case. In the instance of Option A, 1.69 million square feet of ramp space would be required on average daily to receive the C-5, C-141, and C-17 fleets in Saudi Arabia; 0.65 million square feet would be required to receive the CRAF transports.[56] In the instance of Option B, the amount of ramp space for the military-style transports has increased because of the greater ramp requirements of the C-5 over those of the C-17. Option C requires less ramp space for the military-style transports because of their fewer numbers but reflects an increase in the ramp space required for the civil-style transports to accommodate the 747s that would be operated by the Air Force. Clearly, Option A has the least demand on ramp space in theater, although the other options are all within 12 percent in terms of their total ramp-space requirements. Option E requires 6 percent more ramp space than Option A.

Fuel Consumption Is Least for Option E and Most for Option B. Table 4.4 presents the total round-trip fuel consumption for each option. The greater fuel efficiency of the civil-style transport is reflected in the Option E result (Table 4.4).

Options A, B, and D had comparable fuel-consumption results. In Option D, the greater fuel efficiency of the civil-style transport was offset by the added fuel consumed by the tankers assigned to refueling the C-5 fleet.

Number of Flight Crews Arriving in Theater Is Least for Option E and Most for Option D. Flight-crew requirements also vary substantially across options. The substantial bulk-cargo capabilities of the 747, combined with a two-person flight-deck crew (plus a loadmaster), enabled Option E to score lowest in number of crew members arriving daily in theater (Table 4.5). To obtain maximum use of airlift transports, we found that it is most efficient to provide crew rest at the APODs and APOEs, rather than require additional en route stops for changing crews. In the instance of the 747-400F, for example, the aircraft can be flown nonstop from the Southwest Asia APODs to the CONUS APOEs for four of the five APOEs if crews are changed at the APODs. Only one APOE would require a stop for refueling. The C-17,

[56]To deal with the random arrival of transports at APODs, ramp-space requirements for each transport were set at twice the average daily amount that would be needed.

Table 4.4

Fuel Required for Each Enhancement Option, Including the Base Case

Option	Military Aircraft (PAA)				Fuel Consumption[a] (thousand tons/day)
	C-17	C-5C	747-400	KC-10	
A	102	0	0	0	25.5
B	51	51	0	0	25.6
C	51	0	24	0	24.8
D	0	0	24	57	25.5
E	0	0	36	0	22.6

[a]Includes base-case fuel consumption of 18.4 thousand tons/day.

Table 4.5

Flight-Crew Members Arriving in Theater for Each Enhancement Option, Including the Base Case

Option	Military Aircraft (PAA)				Flight Crew Members Arriving in Theater Daily[a]
	C-17	C-5C	747-400	KC-10	
A	102	0	0	0	351
B	51	51	0	0	364
C	51	0	24	0	338
D	0	0	24	57	405
E	0	0	36	0	312

[a]Includes base-case arrivals of 274 crew members per day.

in contrast, requires one stop for one APOE and two refueling stops for the other four APOEs. This crew change consideration also applies to the C-5s in Option D. With aerial refueling, the C-5 can fly nonstop to and from the APODs and APOEs if crews are changed at the APODs and APOEs. Option D has the highest number of crew-member arrivals for two reasons. First, a C-5 crew is larger than a 747-400F crew. Second, the duration of the missions required augmentation of the basic crew with replacement crew members who could share crew duties during the mission.

The Number of Civil-Style Transports Arriving in Theater Is Least for Option A and Most for Option E. The average daily arrivals by civil-style transports is of interest because civil-style transports have greater infrastructure needs at the receiving bases. This includes ground equipment and material-handling equipment. Table 4.6 shows that in moving from Option A to Option E, the number of daily arrivals by civil-style transports, including the 747-400 that would be operated by the Air Force, nearly doubles from 16 arrivals daily to 29. In Option A, all of the arriving civil-style transports are operated by CRAF carriers. Forty percent of the arriving CRAF aircraft are passenger transports. The increases in civil-style transport arrivals from Option A to Options C, D, and E is due to adding the 747-400F to the military airlift fleet.

Table 4.6

Daily Arrivals of Aircraft at Destinations

	Military Aircraft (PAA)				Daily Arrivals[a]		
Option	C-17	C-5-C	747-400	KC-10	Military-Style Transports	Civil-Style Transports[b]	Total
A	102	0	0	0	64	16	80
B	51	51	0	0	60	16	76
C	51	0	24	0	51	25	76
D	0	0	24	57	44	25	69
E	0	0	36	0	38	29	67

[a]Includes base case (38 military and 16 civil arrivals).

[b]Includes 747-400 operated as a military aircraft.

Total Transports Arriving in Theater Is Most for Option A and Least for Option E. The average total number of transports arriving in theater is a reflection of the total burden on air-traffic control (Table 4.6). Perhaps the more interesting aspect of Table 4.6 is the changing mix of arriving aircraft. In Option A, 80 percent of the arriving aircraft are military transports. In Option E, the military aircraft account for 57 percent of the arriving mix. Thus, in moving from Option A to Option E, the Air Force would move from a 80/20 mix to a 57/43 mix. The majority of the arriving transports would still be of the military style.

Benefit Assessments Found Major Differences Between the Options

To the base case, Options A and B add about 1,000 tons per day from the CONUS locations of the Army's five rapid-deployment force divisions to bases in Saudi Arabia. For these same units, Options C, D, and E add 1,300 to 1,400 tons per day.[57]

These throughput results were obtained by analyzing the movement of the five divisions previously cited. For each option, the aircraft mix was checked to ensure that the mix of loads (bulk, oversize, outsize, and passengers) was compatible with the capabilities of the mix of aircraft prescribed by the option. Ensuring that the mix of aircraft could handle the mix of loads was easy, because the Air Force already has a substantial capability to move outsize and oversize materiel. For convenience, the

[57]When we did the initial sizing of the options for the study, we underestimated the performance of the 747-400F in the role of moving bulk cargo. For moving oversize materiel, we would expect the average payloads to be smaller and the total throughput to be correspondingly less, and closer to our original sizing goal of 1,000 tons per day. Another possibility where the throughput for Option E would be slightly less than 1000 tons per day is the case in which (1) bulk cargo missions account for only 25 percent of the mission loads; (2) the 747-400F's average payload for bulk cargo missions is 185,300 (83 percent of the planning factor load of 223,200 lbs); (3) the 747-400F utilization rate is 14 instead of 14.7 hrs per day; and (4) the 747-400F's block speed is 450 instead of 462 kts. Raising the C-17 utilization rate from 12.2 to 12.8 hrs per day would bring the Option A payload up to about 1000 tons per day. If, however, the C-17 is not allowed to refuel at Lajes, throughput for Option A would fall to slightly under 1000 tons per day. At the time of publication in late 1994, the Air Force was more comfortable with the assumptions in this footnote (especially for the first 30 days) than the ones we used in our analysis in 1992.

results of the individual unit movements have been summarized in terms of tons per day of cargo moved.

To check these results against the Gulf War experience, Figure 4.28 explores the sensitivity of the various options in terms of their ability to handle the mix of cargo that was airlifted during the first 30 days of the Gulf War deployment. The figure compares the compositions of Gulf War loads during the first 30 days (August 15 through September 15, 1990) to the composition of the airlift capacity for each of the five options, when those options are used to move the Army's five rapid-deployment force divisions. For example, although Option E has the least amount of outsize capacity, it is still nearly three times the average daily amount of outsize capacity used during the first 30 days for the Gulf War. None of the options has any difficulty dealing with the outsize equipment.

The combination of outsize plus oversize during the first 30 days amounted to 52 percent of the cargo. In the instance of Options C through E, it would be necessary for the military-operated 747-400F to carry some of the oversize equipment in addition to the bulk cargo. Subject to that condition, all of the options can handle the Gulf War mix of loads. The need to carry oversize cargo is a strong reason for selecting a large civil-style transport like the 747-400F or its next-generation replacement, which will be even larger. Smaller transports, such as the MD-11 and the 767, have

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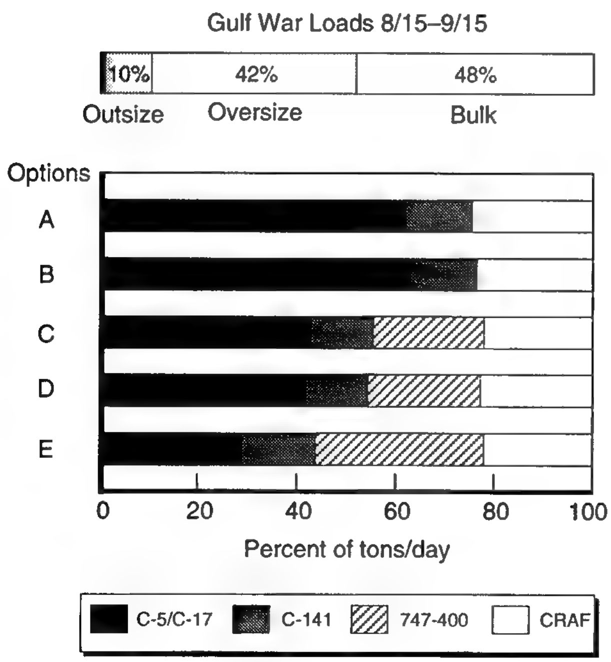

Add to Base Case (PAA)			
Buy			Use
C-17	C-5C	747-400	KC-10
102	0	0	0
51	51	0	0
51	0	24	0
0	0	24	57[a]
0	0	36	0

[a]Assign existing tanker equivalents and add 2.4 crews per C-5.

Base Case (PAA)
• 109 C-5
• 80 C-141
• 28 747-200 CRAF equivalent

Figure 4.28—All Options Can Handle Gulf War Loads

less capability to carry oversize cargo because of the smaller sizes of their doors and cargo cabins.

Deliveries to Short Runways Are Greatest with Option A and Least with Option D and Option E. Table 4.7 summarizes the base-case benefits (and costs) in terms of throughput measured in thousands of tons per day delivered to Southwest Asia.[58] Table 4.8 summarizes the incremental benefits that each option would add to the base case. For example, the mission-cycle analysis assessed the base case as having no capability to deliver cargo directly to airfields with runways shorter than 5,000 ft.

- The addition of Option A to the base case would provide a capability to sustain 26 C-17s landing daily at such airfields and deliver 960 tons daily. This would amount to 33 percent of the daily landings in theater.
- The addition of either Option B or Option C to the base case provides a capability to sustain 13 such landings daily; they could deliver 480 tons daily. For those Options, 17 percent of the daily landings in theater could be directly to such airfields.
- The addition of either Option D or Option E to the base case provides no capability for such landings.

Thus, in moving from Option A to Options B or C, the percentage of aircraft arriving in theater that could be sent directly to airfields with short runways would drop from 33 percent to 17 percent. Options D or E would have no capability for such landings.[59]

The Number of Deliveries of Outsize Is Greatest with Option A and Least with Option E. The mission-cycle analysis assessed the base case as being capable of delivering 1,200 tons per day of outsize cargo to airfields with runways at least 5,000 feet in length. Option A would add 960 tons per day, bringing the total capability to 2,160 tons per day.

With the base case, 18 C-5s could land daily with outsize cargo at airfields with runways as short as 5,000 feet:

- The addition of Option A to the base case would add 26 C-17s landing daily at such airfields, bringing the total landings (C-5 plus C-17) to 44 aircraft per day. This would amount to 55 percent of the daily landings in theater.
- The addition of Option B to the base case yielded similar results, because C-5 aircraft were added to compensate for the decrease in C-17 aircraft.
- The addition of Option C to the base case provides only half of the increase in outsize deliveries that would be provided by Option A.

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[58]Use of current Air Force policies for routing aircraft would slightly reduce the calculated utilization rates and would slightly increase total distances flown. Consequently, the throughput for each option would decline, but only modestly so.

[59]As noted in the discussion of the base case, a C-130 fleet is assumed to continue providing intratheater airlift services. Such a fleet can also make deliveries to short runways, except that it cannot deliver outsize materiel.

Table 4.7

Base-Case Aircraft, Costs, and Benefits

Parameter	Base Case
Number of arcraft	
C-141	94
C-5 A/B	126
747 cargo CRAF	28
747 passenger CRAF	18
Benefits	
Throughput in thousand tons/day to Southwest Asia	
Deliverable to short runways (<5000 ft)	0
Deliverable as outsize	1.20
Total tonnage to theater	2.61
Costs	
Infrastructure costs, average daily	
Ramp space (thousand sq ft)	1,968
Fuel consumed (thousand tons)	18.4
Crew member arrivals in theater	274
Civil-style transports arriving in theater	15.9
Civil-style plus military transports arriving	54.4
Life-cycle cost (for 25 years[a] in billions of 1992 dollars)	48

[a]From 1993–2017.

- Option D compensates for the decrease in C-17 aircraft by providing aerial refueling for the C-5 fleet. That would increase the throughput of the C-5 aircraft in the base case by 370 tons per day.
- The addition of Option E to the base case does not change the number of daily landings at airfields with runways as short as 5,000 feet. The 18 daily C-5 landings at such airfields would account for 27 percent of the daily landings in theater.

Thus, in moving from Option A to Option E, the percentage of aircraft arrivals that could deliver outsize cargo to airfields with runways as short as 5,000 feet would drop from 55 to 27 percent.

Total Tonnage Delivered Is Greatest with Option E and Least with Option A. The total tonnage measure reflects the amount of outsize, oversize, and bulk that could be delivered. Because the pacing constraint on the airlift of materiel for the Gulf War was bulk cargo, the total daily tonnage that each of the five options can deliver to theater airfields is a measure of throughput with significant military value.

The total tonnage results in Table 4.8 are based upon the assumption that bulk cargo accounts for 60 percent of the cargo delivered by airlift, as was the case during the peak month of the Gulf War airlift. Because the 747-400F can carry a significant amount of oversize materiel,[60] the options that include the 747-400F can maintain

[60]Depending upon the extent to which its floor is strengthened and its aft door is widened, the 747-400F can carry at least three-fourths of the oversize materiel (see Volume 3, Appendix B). In theory, CRAF

Table 4.8

Summary of Incremental Costs and Incremental Benefits Attributable to Each Option

Parameter	Options A	B	C	D	E
Number of inventory aircraft					
Buy C-17	120	60	60	0	0
Buy C-5C	0	60	0	0	0
Buy 747-400F	0	0	28	28	42
Use KC-10[a]	0	0	0	59	0
Benefits					
Added throughput in thousand tons/day to Southwest Asia					
Deliverable to short runways (<5,000 ft)	0.96	0.48	0.48	0	0
Deliverable as outsize	0.96	1.04	0.48	0.37	0
Total tonnage to theater	0.96	1.04	1.41	1.30	1.39
Costs					
Added infrastructure costs, average daily					
Ramp space (thousand sq ft)	370	637	521	625	506
Fuel consumed (thousand tons)	7.1	7.2	6.4	7.1	4.2
Crew member arrivals in theater	77	90	64	131	38
Civil-style transports arriving in theater	0	0	8.5	9	12.8
Civil-style plus military transports arriving	25.6	21.4	21.3	14	12.8
Life-cycle cost (for 25 years[b] in billions of 1992 dollars)	39	43	30	36	15

[a]To refuel C-5s.

[b]For 1993–2017.

significant delivery levels even when bulk cargo needs are a lower portion of total cargo needs. For example, Option E matches the deliveries of Option A even if bulk cargo is only 38 percent of the total. During the first 30 days of the Gulf War airlift, it was 48 percent.

The base case was assessed as being capable of delivering 2,610 tons per day of cargo to airfields in Southwest Asia with runways at least 10,000 ft long.

- Option A would add 26 C-17s landing daily at such airfields, bringing the total landings to 80 aircraft per day. Option A would add 960 tons per day, bringing the total capability to 3,570 tons per day.
- Option B yielded similar results, because C-5 aircraft were added to compensate for the decrease in C-17 aircraft.
- Option C provides an additional 1,410 tons per day, bringing the total capability to 4,020 tons per day.
- Option D compensates for the decrease in C-17 aircraft by providing aerial refueling for the C-5 fleet and adding 747-400F aircraft. That adds 1,300 tons per day to the base case, bringing the total to 3,910 tons per day.

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transports can also carry oversize cargo; however, varying floor strengths made that problematic during the Gulf War airlift, and consequently, CRAF was used only to carry bulk cargo.

- The addition of Option E to the base case adds 1,390 tons per day, bringing the total capability to 4,000 tons per day.

Thus, in moving from Option A to Option E, the total throughput capacity for the Southwest Asia scenario moves from 3,570 to 4,000 tons per day.

Cost-Benefit Ratios Are Very Sensitive to Main Needs

Because there are multiple measures of both costs and benefits, cost-benefit ratios provide a useful way to compare the incremental effects attributable to the options. For example, taking the increase in total tonnage attributable to an option as a measure of benefit, the life-cycle cost remaining (attributed to the option) divided by the total tonnage yields the cost-benefit ratio in the last column of Table 4.9. The smaller this number, the more attractive the alternative in an economic sense relative to the throughput consideration. A complete set of cost-benefit ratios is computed from the data in Table 4.8 and displayed in Figures 4.29 and 4.30. For example, using life-cycle cost as the cost, the cost-benefit for Option A—if the benefit is "direct deliveries to short runways"—is determined by dividing the 25-year life-cycle cost ($39 billion) by the 960 tons per day to get a life-cycle cost of $41 billion to provide a standard benefit of being able to deliver 1,000 tons per day during a major airlift.

The ratios of most interest depend upon what measure of benefit is perceived to be the main rationale for further investments in the military airlift fleet:

- If the main unsatisfied need is to acquire a capability to deliver directly to short runways, then the cost-benefit ratios of interest can be found in the left columns of Figures 4.29 and 4.30.
- If the main unsatisfied need is to acquire additional capability to deliver outsize materiel, then the cost-benefit ratios of interest can be found in the center columns of Figures 4.29 and 4.30.
- On the other hand, if the main unsatisfied need is to deliver tons of bulk and oversize materiel, and it is acceptable to make such deliveries at a regional airfield with long runways, then the right columns of Figures 4.29 and 4.30 are of interest.

Table 4.9

Throughput and Cost for Options

Option	Military Aircraft (PAA) C-17	C-5C	747-400	KC-10	Throughput Increase (Δ tons/day)	Options' Life-Cycle Cost[a] ($ million)	Marginal Cost ($ milllion/ Δ tons/day)
A	102	0	0	0	960	39,000	41
B	51	51	0	0	1,040	43,000	41
C	51	0	24	0	1,410	30,000	21
D	0	0	24	57[b]	1,300	36,000	28
E	0	0	36	0	1,390	15,000	11

[a]1992 $.

[b]Add 2.4 crews per C-5.

If direct delivery to short runways would be the main need,[61] Options D and E are not applicable because they cannot satisfy that need. Option A is clearly preferred if the size of the unsatisfied need is such that 26 direct deliveries from CONUS to Southwest Asia would be required daily.[62] If the need is half that size, then Option C is attractive for its lower cost.

If outsize deliveries are the main unsatisfied need, then either Options A or B yield comparable least-cost performance in terms of the cost-benefit ratios (Figures 4.29 and 4.30). Option E is not applicable, because it produces no added outsize capability.

If total tonnage to theater is the main unsatisfied need, then Option E presents an interesting possibility for substantial cost savings. For life-cycle costs, Figure 4.29 shows a nearly four-to-one cost-effectiveness advantage for Option E (747-400) over Option A (C-17). In our scenario, the 747-400 is able to be a significant and highly efficient contributor, because it is doing what it does best, which is movement of bulk cargo. However, during the first 30 days of a deployment, such as that for the Gulf War, the 747-400 would also have to carry some oversize cargo.

Figure 4.29 shows a significant difference in cost-benefit ratios as the mix of military- and civil-style transports shifts from adding only military-style transports to the base case to the alternative of adding only civil-style transports. In going from one extreme to the other, the cost-benefit ratio changes by nearly a factor of four. Put another way, the military-style transport is nearly four times more costly than the civil-style transport, assuming each style is capable of handling the cargo to be moved and is capable of delivering the cargo to an equally suitable destination. Of course, there are scenarios where that simply would not be the case. Thus, in such scenarios, additional movement of the cargo would be required to put it in the needed location. The trade-off, therefore, is between nearly a factor of four advantage in cost-benefit ratio versus the increased delivery flexibility offered by the military-style transport.

Our analysis of changes in airlift demands (Chapter Two) and the supply of civil airlift (Chapter Three) supports the presumption that the Air Force most needs to increase its ability to move bulk and oversize materiel to the theater. An alternative presumption would be that it most needs to move materiel directly to airfields with short runways. Under the alternative presumption, Option A is the preferred option.

For both the C-17 and the C-5, there is a further consideration about how often the United States would operate large transports into small airfields, especially in situations where the aircraft may be at greater risk of hostile actions than at rear locations.

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[61] Direct delivery to short runways is addressed, because it is one of the reasons underlying the development of the C-17.

[62] Option A has the capacity for about 26 deliveries daily, given the assumptions and ground rules underlying our analysis.

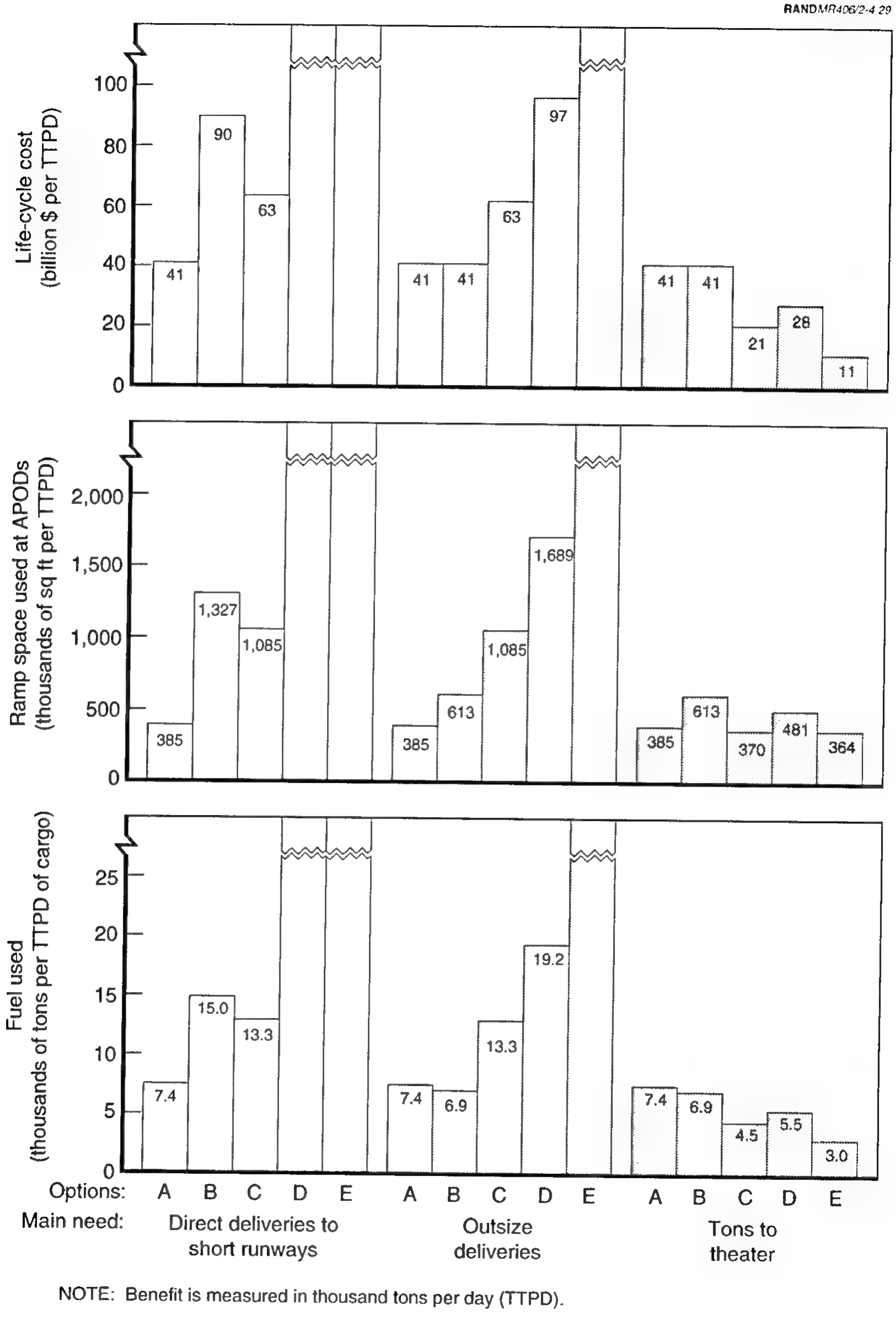

Figure 4.29—Cost-Benefit Ratios Attributable to the Incremental Effects of the Options for Life-Cycle Cost, and Daily Use of Ramp Space and Fuel

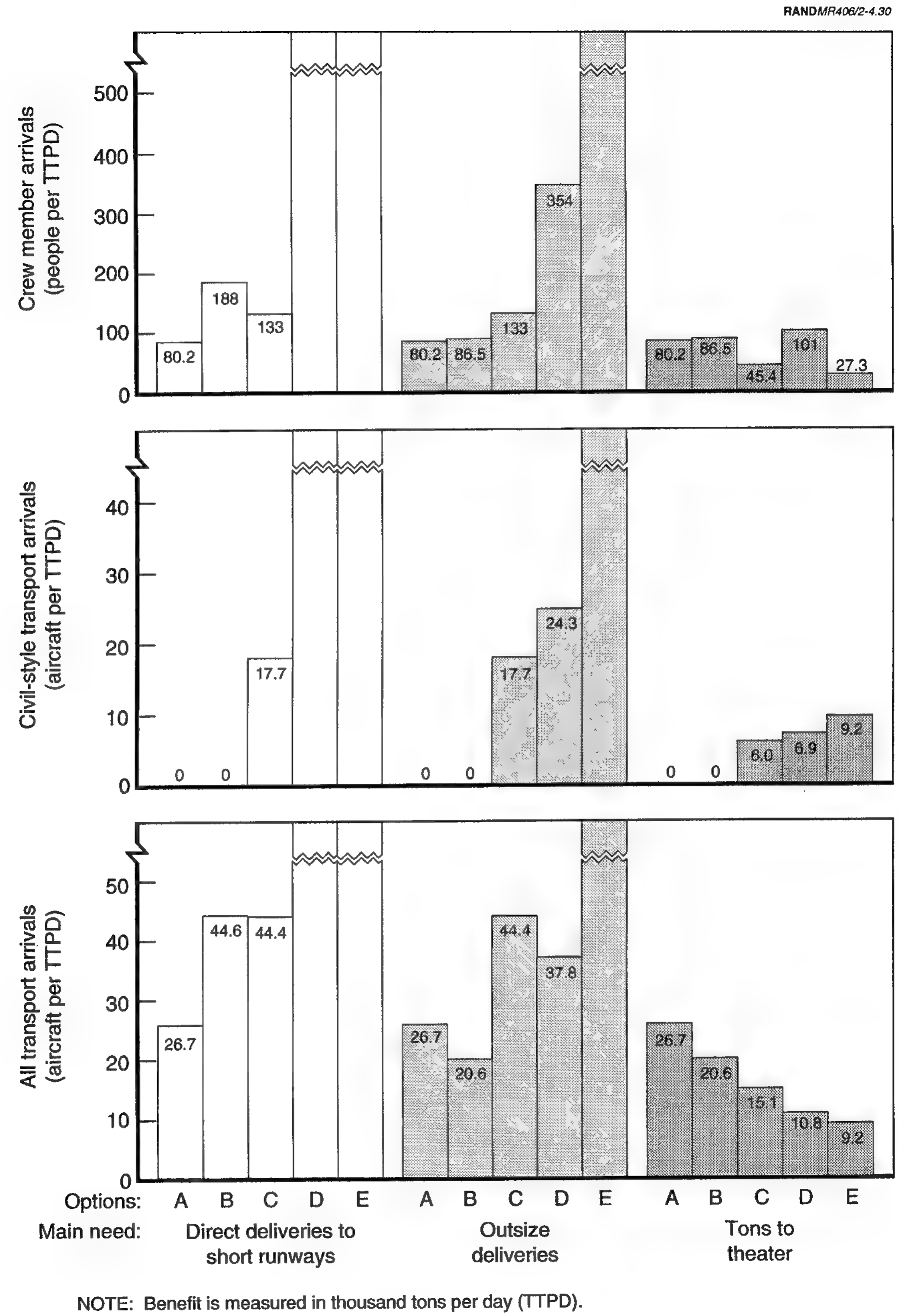

Figure 4.30—Cost-Benefit Ratios Attributable to the Incremental Effects of the Options for Daily Arrivals of Crew Members and Transports

Different Perspectives About the Governing Constraints Yield Widely Different Answers

There are many potentially limiting constraints that could materially shift one's view of the preferred option. For example, if a scenario requires the ability to move a large amount of outsize equipment by air, Options A, B, and C are clearly preferred to Options D and E (Figure 4.31). On the other hand, if the limiting constraint is the movement of either bulk cargo or people, then Options C, D, and E are preferred over A and B. If ramp space is a limiting constraint, Options A, C, and E are preferred in terms of the tons delivered per square foot of ramp space. On the other hand, if fuel availability at the destination airfield is the most limiting constraint, Option A has the greatest requirement for fuel, while Option E, with its heavy emphasis on civil-style transports, has the lowest requirement for fuel. If runway strength is the limiting constraint, then Option D is preferred, because the C-5 can operate on weaker runways than either the C-17 or the 747-400 (see Chapter Five). On the other hand, if runway length is the limiting constraint, the short-field capability of the C-17 shifts the preference to Options A and B. If operating under hazardous conditions is the limiting constraint, the greater maneuverability of the military-style transports

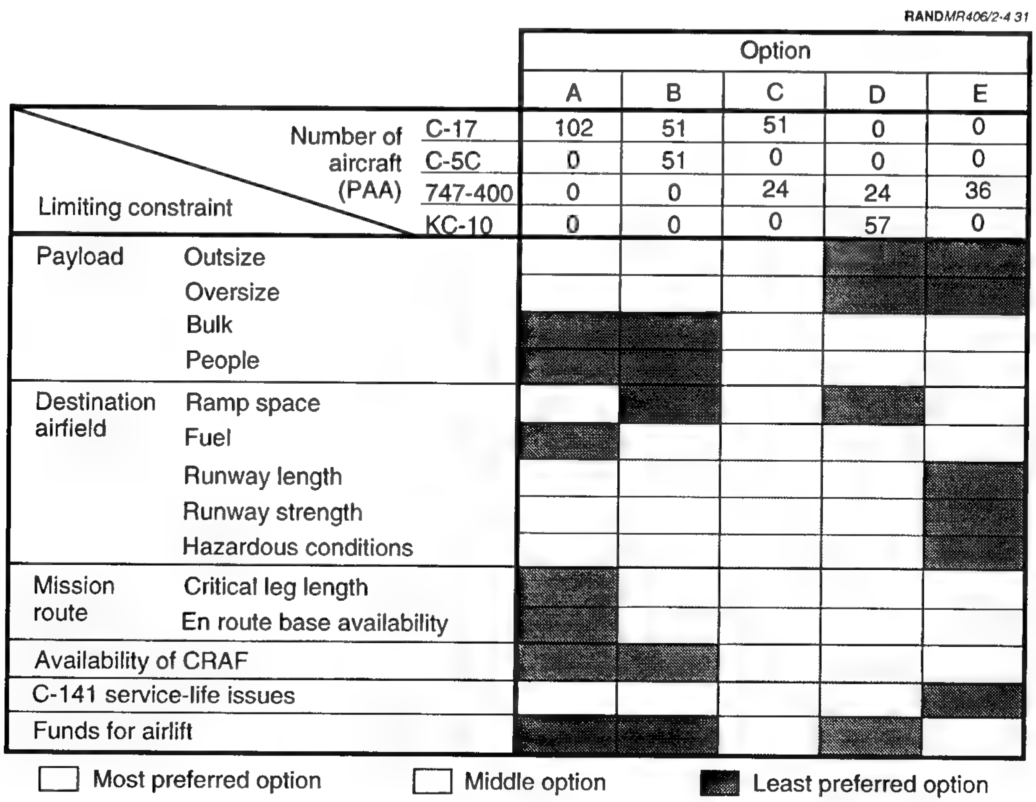

Figure 4.31—No Single Option Is Dominant for All Considerations

places the preference on Options A, B, and C. If critical leg length or en route base availability are the limiting constraints, the options with the civil-style transports (D and E) become more attractive.

If there are concerns about either preserving the availability of CRAF or its dependability, having some civil-style transports in the Air Force's airlift fleet makes Options C, D, and E attractive. Concerns about either the practicality of extending the C-141's service life or the potential loss or disruption of the military airlift capability provided by the C-141 would lead one to prefer Options A, B, and D over C and E. If the limiting constraint is the availability of funds for airlift, the economic attractiveness of Option E makes it the preferred option.

If there are concerns about both the life of the C-141 fleet and the availability of funds for the airlift mission area, the choice is more difficult. From a fiscal perspective, using Option E to replace two-thirds of the fleet appears attractive. The question then becomes, what should be done about the remaining third? Volume 3, Appendix F, identifies several possibilities that could be explored.

Because no single column is dominantly shaded as either the most preferred or the least preferred, there are no dominant outcomes given the considerations in Figure 4.31. Option C does emerge, however, as a prospective compromise, because it bears none of the "least preferred" shadings. Option C, however, only reduces the costs of Option A by a modest amount. Substantial cost savings come only with Option E. Because of the large cost difference between Options A and E, we need to take a closer look at the need for outsize and oversize airlift capabilities.

Outsize Cargo Is Not a Dominant Constraint. Because most outsize materiel is used by the Army, it is instructive to review the Army's assessment of their outsize lift requirements for the five rapid-deployment divisions.[63] Table 4.10 shows that most of the C-5 missions are needed to move the armored division and the mechanized division. Table 4.11 shows the tonnage this deployment entails.[64] We have assumed that in addition to the unit movement tonnage there is a comparable amount of bulk cargo in the form of sustainment materiel, as was seen during the Gulf War airlift. Table 4.11 also shows the closure times for moving the materiel for this deployment. The final closure time for all materiel is shown in the last column of the table[65] as it was calculated by our closure time model.[66] The other times in the table are for a hypothetical situation where all of the outsize is moved first, then the

[63]The outsize lift requirements represent loads carried on an outsize-capable transport. The loads placed on each individual aircraft will include at least one item of outsize materiel and may include oversize and bulk materiel and personnel, depending upon the space available and the unit's need to keep certain materiel and personnel on the same aircraft. Similarly, oversize mission loads may include some bulk and personnel.

[64]The oversize missions identified in Table 4.11 include only oversize, bulk, and personnel. The bulk missions include only bulk and personnel. The outsize missions include all classes of cargo and personnel.

[65]Although the closure times are about four months for this evaluation scenario, we are not suggesting that airlift would be the sole deliverer of forces for such an extended period.

[66]The model allocates transports to the five deployment streams in a manner that ensures closure of all five divisions on the same date. It also ensures a steady flow of loads for each division. For an individual division, its outsize mission materiel is assigned to available C-5s and C-17s before oversize mission ma-

Table 4.10

Missions Required to Move the Unit Equipment for the Army's Five Types of Rapid-Deployment Divisions

	Transport Type		
Division	C-5	C-141	CRAF 747-200 Passenger Equivalent
Light infantry	18	618	15
Armored	787	1,032	15
Air assault	82	1,222	26
Airborne	21	893	22
Mechanized	757	1,065	16
	1,665	4,830	94

[a]Twenty-nine percent of the oversize loads must be carried by the 747-400F. For missions with oversize loads, the average payload for the 747-400F was assumed to be 145,000 lbs.

Table 4.11

Closure Times for Moving the Army's Five Rapid-Deployment Divisions Entirely by Airlift

	Mission type			
Parameter	Outsize	Oversize	Bulk	Total
Tons to be moved	115,000	133,000	248,000	496,000
Days required to complete the movement				
Option A	53	94	139	139
Option B	51	91	136	136
Option C	68	114	123	123
Option D	73	120	127	127
Option E	96	126[a]	126	126

oversize and finally the bulk. This exercise illustrates the relative capacities of the different options to move outsize and outsize plus oversize materiel. By adding Option A to the base case, the outsize mission materiel could be moved in just 53 days. By adding Option E instead, the closure time for the outsize is almost doubled to 96 days. Thus, if flexibility to move outsize materiel is a strong need, and if even Option C provides insufficient capacity to move outsize materiel, then Options A and B would be preferred over the other options.

There is more to a deployment, though, than just moving outsize materiel. Indeed, the oversize materiel must be moved along with the outsize to maintain the combat capability of individual units comprising the divisions. Table 4.11 shows that with Option A, the outsize and the oversize would be moved in 94 days, whereas with Option E it would take 126 days. Moreover, with Option E, 29 percent of the oversize materiel would have to be moved by the 747-400F.

teriel is assigned to those outsize-capable transports. Similarly, oversize mission materiel is assigned to oversize capable transports before bulk.

But again, there is more to a deployment than just moving the outsize and oversize materiel for combat units. There is also bulk materiel. When the bulk materiel is added, the closure time preference switches from Option A to Option E. With Option E, the five divisions are deployed almost two weeks sooner than with Option A.[67]

If there is a convincing requirement for outsize cargo to be a dominant constraint in governing the airlift mix, the logic for that requirement is neither evident from this research nor does it seem to have been established by the service needing most of the outsize airlift capacity.

On the other hand, because closure of outsize and oversize takes longer for Options D and E than for Option A, moving from Option A to either D or E sacrifices responsiveness in terms of being able to quickly meet changes in needs for delivering outsize and oversive cargo. Thus, although overall closure times favor Option E over Option A, Option A has greater ability to respond to shifts in the load mix for which outsize needs might increase relative to oversize needs for a period of time. Although the greatest operational flexibility is provided by Option A, fiscal considerations must also be considered (below).

If Airfield Access Is a Dominant Constraint, Further Research Is Needed. If direct deliveries to airfields with short runways (less than 5,000 ft long) is a dominant constraint, Chapter Five shows why further research is required to understand whether the C-17 really increases such access to a militarily significant extent.

If Funding Is a Dominant Constraint, the Mix Needs to Shift. As Figures 4.32 and 4.33 illustrate, large civil-style transports, such as the 747-400F, are especially efficient at moving large loads over long distances. Even if the large civil transport were owned and operated by the government, it could deliver bulk cargo at almost one-fourth the life-cycle cost incurred by the C-17 transport (Figure 4.32). It could also move passengers for one-fourth the life-cycle cost of the C-17 (Figure 4.33).

Because flexibility clearly favors A, and affordability clearly favors E, on what basis can we make a choice? If we assume that the total investment for the airlift mission area is constrained, we can ask how much the DoD is willing to lower the overall capacity of the airlift fleet to buy the additional flexibility of Option A. Put another way, is giving up four tons per day of limited delivery capacity (bulk and some oversize only) worth having one ton per day of flexible capacity (all types of loads and delivery modes)? Because the CINCs need both capacity and flexibility in airlift deliveries, this is a tough choice. That is precisely why we chose to use a tough scenario for evaluating delivery capabilities of alternative fleets. Relative to that scenario, Option E delivers the load. It is not as flexible as Option A, but it gets the job done at a lower cost.

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[67]Moreover, given the timelines (and assuming an available port), better closure could be obtained through sealift.

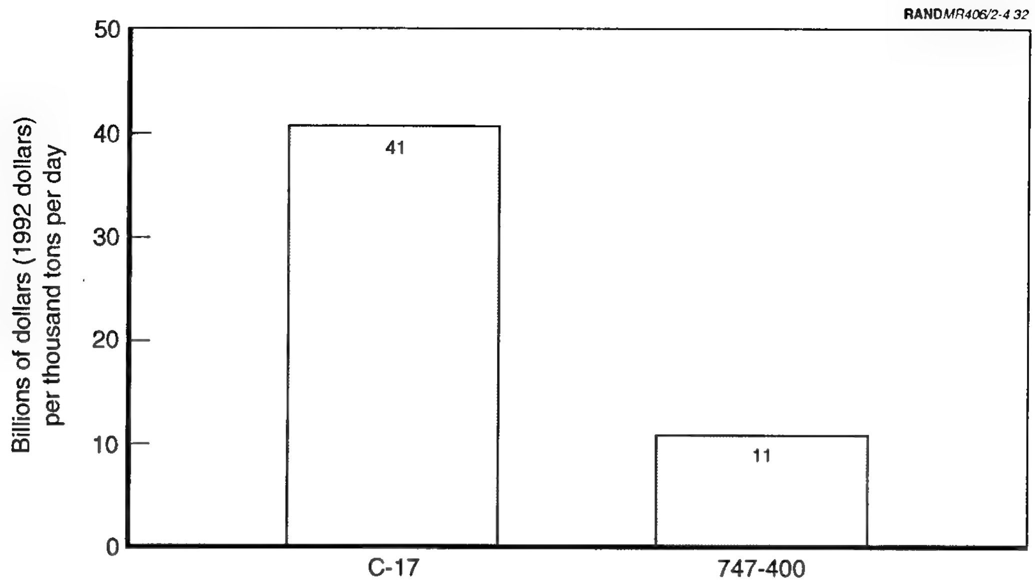

Figure 4.32—Life-Cycle Cost (25 Years) for the Capacity to Airlift Cargo to Southwest Asia

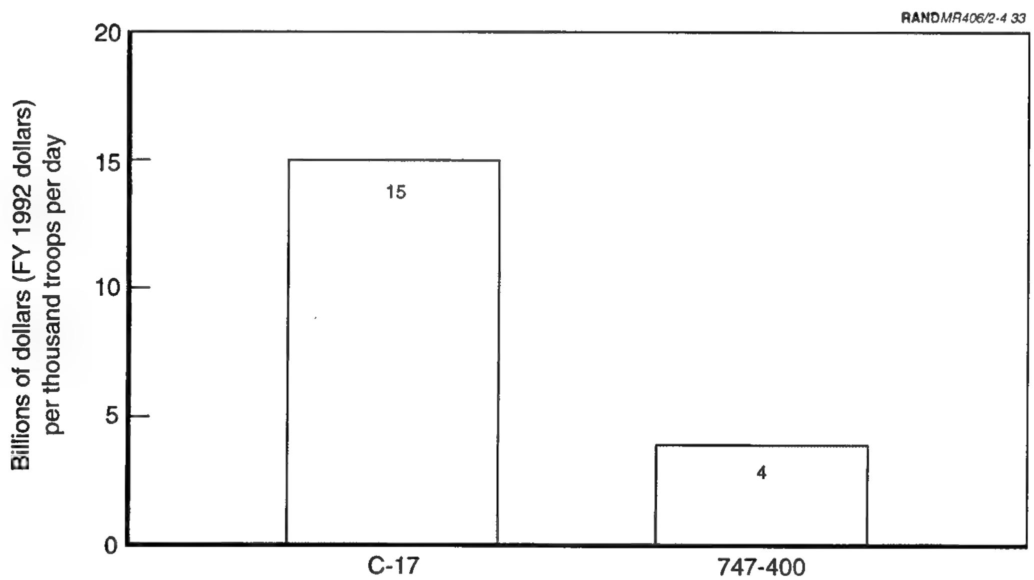

Figure 4.33—Life-Cycle Cost (25 Years) for the Capacity to Airlift Troops to Southwest Asia

If we assume that airlift capacity needs to be maintained at about current levels, if not higher, Option E appears to be the most viable alternative in view of satisfactory performance and its superior affordability during a period of tight resources and difficult choices facing the Air Force in all mission areas.

Civil-Style Transport Provides Needed Throughput

Deliveries to Airfields with Short Runways. Table 4.8 suggests that there may be significant differences among the options in their abilities to deliver typical deployment loads to airfields with short runways. We found, however, that less than 10 percent of the airfields usable by the C-17 could not be used by the C-5, because the runway is too short or too narrow.[68] Similarly, less than 10 percent of the C-5–usable airfields cannot be used by the C-17, because the runway is too weak. Thus, because the C-17 adds little to the base case's access to airfields, the military value of the first measure of throughput (to short runways) is fairly limited.

Deliveries of Outsize Cargo. The base case already has a significant delivery capability for outsize deliveries. For example, even though Option E fails to add to that capability, our analysis of adding Option E to the base case shows that the five divisions complete their deployment in slightly less time with Option E than with any other option. To do this, the 747-400F fleet in Option E had to deliver 29 percent of the oversize and much of the bulk cargo in our analysis scenario. The CRAF cargo transports delivered only bulk cargo. Thus, because the outsize requirement was satisfied by all options in our analysis, and because we used a scenario with significantly more outsize than is usually the case, the military value of the second measure of throughput (outsize deliveries) is also fairly limited.

Total Tonnage to Theater. The total tonnage measure reflects the amount of outsize, oversize, and bulk that could be delivered. Because the pacing constraint on the airlift of materiel for the Gulf War was bulk cargo, the total daily tonnage that each of the five options can deliver to theater airfields is a measure of throughput with significant military value. The total tonnage results in Tables 4.8 and 4.9 are based upon the assumption that bulk cargo accounts for 60 percent of the cargo delivered by airlift, as was the case during the peak month of the Gulf War airlift. Because the 747-400F can carry a significant amount of oversize materiel, the options that include the 747-400F can maintain significiant delivery levels even when bulk cargo needs are a lower portion of total cargo needs. For example, Option E matches the deliveries of Option A even if bulk cargo is only 38 percent of the total. During the first 30 days of the Gulf War airlift, it was 48 percent.

The next chapter shows, however, that, because of runway limitations (length, width, and strength), a 747-400F can deliver to only one-third the number of airfields that could be used by the C-5 and the C-17. However, regardless of which option might be selected, the Air Force still requires at least one airfield to accommodate the CRAF transports in the base case. The base case requires 15.9 daily arrivals in theater by the CRAF 747-200 passenger transports and the CRAF 747-200F cargo transports. Furthermore, given the existence of at least 536 airfields around the world that can accommodate the 747, there is unlikely to be a major regional contingency or crisis where the 747-400F could not make deliveries to the general region of interest.

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[68]Even with the AMC approach of using an LCN of 20 for both the C-5 and the C-17, we found that less than 25 percent of the airfields usable by the C-17 could not be used by the C-5 because the runway is too short or too narrow.

To the base-case capability of 2,610 tons delivered daily, Options A and B add about 1,000 tons per day from the CONUS locations of the Army's five rapid-deployment-force divisions to bases in Saudi Arabia. For these same units, Option C, D, or E would add 1,300 to 1,400 tons per day to the base case.

Civil-Style Transport Minimizes Costs

Infrastructure Costs. The ramp-space (MOG) requirements for Option E are comparable to those for Option A after adjusting for the fact that Option E delivers 45 percent more cargo. Option E requires 364,000 sq ft of ramp space in theater per 1,000 tons delivered daily, compared to 385,000 sq ft for Option A. Option E has a clear advantage, however, in only requiring 3,000 tons of fuel daily to deliver 1,000 tons of cargo, versus the 7,400 tons for Option A. Significantly fewer crew members need accommodations for Option E than for the other options. And significantly fewer total transports arrive in theater for Option E than Options A, B, and C. The only cost measure in which Option E is at a disadvantage is the number of civil-style transports arriving in theater. Option E produces 12.8 additional arrivals. If the Option E fleet were reduced in size to deliver the same amount of cargo as the Option A fleet, the number of additional arrivals would decline from 12.8 to 8.8. This is only about a 50-percent increase in the base-case arrivals for CRAF's civil-style transports.

Life-Cycle Costs. Option E, at $15 billion, is nearly one-third the cost of Option B or Option A. The cost difference is so great because a single 747-400F costs less to procure than a single C-17, even though the 747-400F carries much more payload (see Figure 4.16), flies farther, and flies faster.[69] If we assume that the C-5 fleet could carry the outsize cargo, a fleet of 42 747-400Fs can deliver 45 percent more cargo than a fleet of 120 C-17s.[70]

Option B, with a 25-year life-cycle cost of $43 billion (1992 dollars), is the most costly. Next is Option A, with a 25-year life-cycle cost of $39 billion (cost remaining as of FY 1993).[71] Option D proved to be surprisingly costly, given that no military-style transports are procured under that option and that the cost of buying tankers was also excluded. Aerial refueling, as was discussed in Chapter Four, is costly.

Considering all five dimensions of cost, Option E is the least costly in three dimensions and is tied with Option A in one dimension (ramp space). Option A is the least costly for one dimension (civil-style transport arrivals). Given the enormous difference in life-cycle costs, we find that Option E is most attractive.

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[69]Because of its higher cruise speed and longer range between refuelings, the 747-400F had an average block speed of 462 kts in contrast to the C-17's 409 kts.

[70]The range capability of a large civil-style transport is superior for several reasons: (1) It does not bear the weight penalties associated with self-contained ramps and strong floors to withstand the concentrated loads of very-heavy tracked vehicles (such as tanks); (2) it does not require a ramp and doors that open in flight for air drop, allowing its aft fuselage to be better tapered to minimize drag; and (3) unlike the single large cargo cabin in the military-style transports, the civil-style transports have a main deck plus a belly compartment that allow for full use of the fuselage's volume when carrying either passengers or cargo.

[71]Given the potential errors in the estimates of costs, the 10-percent difference in costs for Options A and B is probably not significant.

To illustrate this point, Figure 4.32 shows the life-cycle cost per standard unit of capability where we define 1,000 tons delivered daily as one standard unit. It illustrates a nearly 4-to-1 cost-effectiveness advantage for Option E (747-400F) over Option A (C-17). By viewing the results in Table 3 in terms of such a cost-benefit ratio, we have adjusted for the fact that Option E delivers more capability (1,390 versus 960 tons per day) than Option A.

Discounting costs at a 5-percent rate increases the nearly four-to-one advantage of Option E (Figure 1.7) to a 4.2 advantage. At a 10-percent discount rate, the advantage becomes 4.5 to one in favor of Option E.

Although the research focused on a Southwest Asia scenario, similar results would emerge for large-scale airlift operations in support of major regional contingencies in other parts of the world where major airports would be available for use by civil-style transports. For westbound deployments, for example to Korea, the critical leg lengths and the prevailing headwinds make Option E even more attractive because of the range capability of the 747-400.

ESTIMATED MIX INCREASES NEEDS FOR IMPROVED C4

The airlift job for a very large crisis can be thought of as a need to move a mix of cargo and personnel from one mix of bases to another mix of bases by using a mix of transports and any available tankers that might be borrowed to boost airlift capacity. The problem then becomes one of matching transports with loads, bases, and tankers. Some transports can take off from bases with short runways and land at bases with short runways. Other transports need bases with long runways. Such an approach to airlift, however, increases the pressure on command, control, and communication to match airlift and tanker resources (including infrastructure) with needs continuously. Upgrading command and control, as well as communication and computer systems, is crucial to getting the most from airlift and tanker resources.

Moreover, if the DoD increases its dependence upon civil-style transports, the value of better C4 will be even greater if it allows loads to be prepared to exploit the capabilities of particular types of transports. For example, the private sector routinely prepares pallets and loads containers tailored to provide maximum utilization of the available volume within the transport. For example, a 10- to 20-percent increase in payload can be achieved by knowing what type of transport will be carrying a particular load. C4, therefore, has many ways to significantly leverage the DoD's investment in airlift. The value of improved C4 must, of course, be weighed against the cost of achieving the improvements. It seems, however, that the ability to deliver more with a given set of airlift resources—and the cost of those resources—should justify a significant investment in improving C4.

ESTIMATED MIX IDENTIFIES NEEDS TO REASSESS AIRLIFT CAPACITY AND C-17

The trends in both airlift demands and the supply of civil airlift point strongly in the direction of a need to increase total tonnage capacity. Thus, the best estimate of the right mix needs to include a significant role for a civil-style transport that would be operated by the military. Trends from the Gulf War and this research also clearly indicate that the amount of airlift capacity that can be applied to a major regional contingency is less than what the traditional planning factors have indicated. Together these trends point to the need to reassess airlift capabilities and to reconsider the C-17 program.

Reassess Capabilities for a Major Airlift

The daily delivery of 3,570 tons over an average distance of 7,000 n mi for the Southwest Asia deployment scenario yields a daily airlift rate of 25 million ton-miles per day.[72] This is about half of the daily airlift rate of 49 million ton-miles per day calculated in Table 1.1 for the nation's daily airlift capacity.

Figure 4.34 draws upon the results of Chapters Three and Four to reassess the nation's daily airlift rate. The numbers with the line drawn through them are planning

RANDMR406/2-4.34

Aircraft	Air Force planning factors that determine the daily airlift rate					Daily airlift rate[c] (million ton-miles per day)
	Average block speed[a] (kts)	Average utilization rate[b] (hrs/day)	Average payload (tons/aircraft)	Average productivity (miles with cargo)/(miles without cargo)	Average number of aircraft	
Military transports						
C-5	~~423~~ 424	~~11~~ 7.4	~~68.9~~ 65.1	0.47	109	~~16.4~~ 10.4
C-141	~~410~~ 409	~~12.5~~ 11.7	~~27.5~~ 24.5	0.47	234	~~15.5~~ 12.9
C-17	~~440~~ 409	~~15.65~~ 11.3	~~48.3~~ 37.4	0.47		
Total					343	~~32~~ 23
Civil transports						
Wide body	450	10	74.55	0.47	~~82~~ 22	~~12.9~~ 3.4
Narrow body	440	10	36.2	0.47	~~59~~ 20	~~4.4~~ 1.5
Total					~~141~~ 42	~~17~~ 5
Total military plus civil					~~484~~ 385	~~49~~ 28

[a]2,500 n mi missions.
[b]For surge conditions.
[c]Rate = speed x utilization x payload x productivity x aircraft.

Figure 4.34—Current Theoretical Capacity for Airlift Based upon Our Analysis of the Southwest Asia Scenario

[72]For the Southwest Asia scenario, the average distance flown from APOEs to APODs for the five deployment streams was 7,500 n mi.

factors from Table 1.1 that we found to be in need of the indicated adjustments based upon this research. The average block speeds for the military transports are from Figure 4.22. The average utilization rates are from Figure 4.23 for the case of average ground times observed during the Gulf War. Average payloads are from Figure 4.18. The numbers of CRAF aircraft are for the 1992 CRAF, assuming a Stage I activation of passenger aircraft and a Stage II activation of cargo aircraft. These are the CRAF conditions used in the analysis in this chapter. For the CRAF transports, our analysis did not find a need to change the factors for the block speeds, payloads, and utilization rates. This partly reflects the greater attention that was devoted to the military airlift fleet. The resulting assessed daily airlift rate is 28 million ton-miles per day. This, however, is for all aircraft. Assuming that at most 75 percent could be assigned to a major regional contingency, such as the Gulf War, yields an adjusted capability of 21 million ton-miles per day.

During the peak month of the Gulf War airlift, the daily airlift rate was 18.9 million ton-miles per day. CRAF contributed slightly more than Figure 4.34 projects due to the participation of aircraft that were offered above and beyond those required by the CRAF activation. On the other hand, military airlift contributed less because of lower utilization rates.

Because our assessment of the airlift capacity that can be realistically applied to supporting a major regional contingency is only 43 percent of the theoretical capability that planning factors have previously suggested (Table 1.1), it is even more important to ensure that future investments in airlift yield the most benefit for the dollars invested.

Another implication that can be drawn from Figure 4.34 concerns the numbers of C-17 and C-141 aircraft that must be in the inventory to maintain the current airlift capacity. Based on the Air Force's FY 1992 plan, calling for the retention of 80 PAA C-141s, it would need 105 PAA (124 total inventory) C-17s. This is very close to its FY 1992 plan to buy 120 C-17s.

Reconsider the C-17 Program

Through FY 1992, funds had been authorized to procure 14 flight vehicles, some for test, others for the first C-17 squadron. There are three possibilities for reducing the quantity of C-17 aircraft to be procured:

- Maintain reduced rates of production for several years.
- Stop production and resume after several years.
- Stop the acquisition program.

Advantages of Slowing Production. During a production slowdown (or stop), a lead-the-fleet squadron could be equipped with about ten aircraft apart from those involved in the development test program:

- Such a squadron could begin exploration of how the aircraft's unique capacity to carry outsize equipment quickly over international distances and operate into

austere fields may be integrated into the evolution of forces that might uniquely use such an airlift capability.

- Such a squadron could verify reliability, maintainability, and availability (RM&A) characteristics specified in the C-17 warranty. Although the existence of an RM&A warranty provides some level of assurance that contractual values in these matters will be achieved, the economic reality of the aerospace industry—and in this instance, the producing company—suggests it may be in the government's interest to acquire some level of evidence that needed levels of RM&A performance are being achieved prior to high-rate production. If shortfalls in RM&A should prove to exist, the production slowdown or hiatus could provide an opportunity for development and incorporation of design modifications to ensure that subsequent production articles have suitable RM&A characteristics. The importance of such characteristics was illustrated during the Gulf War as the military transports had a continuing need for higher levels of maintenance than the civil transports.

Disadvantages of Slowing Production. The disadvantages include the following:

- The full availability of a C-17 fleet's operational capabilities would be delayed.
- Lengthening the overall production time increases the program's total cost of overhead.

Advantages of Stopping Production. The advantages are the following:

- Stopping production for a period of about three years would provide a significant decrease in the Air Force's need for near-term procurement funds.
- The Air Force would have an opportunity to reevaluate the design characteristics of the C-17 and incorporate those modifications that would best suit the aircraft for the evolving world situation.
- Design changes would need to be retrofitted to fewer aircraft.

Disadvantages of Stopping Production. The disadvantages are the following:

- Restarting production adds significant costs to the total program. Such costs could include disassembly of tooling, storage, and reassembly or relocation to another site; retraining of work force because of the loss of skilled workers; loss of learning efficiency; loss of vendor base, requiring requalification and reestablishment of learning efficiency; recreation of lost or obsolete documents, specifications, technical manuals, etc.; potential loss of warranty coverage for RM&A; extending the flight-test program; added RDT&E costs to extend development; and reopening of a contract that exposes the Air Force to sharing or funding the contractor's cost overrun for the current development effort.
- Production may never be restarted.

Advantages of Stopping the Acquisition Program. Ending the C-17 program would conserve funds needed for the production of an alternative transport, such as the

747-400F. Because supporting a small fleet of C-17s would be costly, stopping soon would avoid the possibility of later having a very small and costly fleet.

Disadvantages of Stopping the Acquisition Program. Stopping the C-17 program would result in regrets if the C-17 could prove that it would have a uniquely worthwhile capability to access airfields having significant military value. The issue of airfield access is dealt with further in Chapter Five.

WHAT IF SURPRISES CHALLENGE THE SELECTED MIX?

Although a Southwest Asia scenario was used for the research, similar results would emerge for large-scale airlift support of major regional contingencies in other parts of the world where airports would be available for use by civil-style transports, as must be the case to use CRAF. However, westbound deployments, such as to Korea, would increase the opportunities for the large civil-style transports to take advantage of their superior range capabilities because of the long flight distances and headwinds involved.

Assume that the Air Force selects Option A. What if someday it confronts a scenario where large amounts of bulk cargo need to be shipped rapidly by air? The main recourse would be to activate CRAF and risk the possibility of undermining future commitments by large air carriers. On the other hand, suppose that someday it faces a scenario where long flight distances and or headwinds would force a reduction in C-17 payloads? The main recourse would be to divert tankers from other commitments to provide aerial refueling for the C-17s.

Now consider the alternative course of pursuing Option E. What if someday the Air Force has a situation where access to 747-suitable airfields is denied in the area of interest? The main recourse would be to fly the 747-400F as far as airfield access would permit and then transfer its loads to military transports for completion of the mission. Or, suppose that "someday" it confronts a scenario where large amounts of outsize cargo need to be shipped by air? The main recourse would be to divert tankers from other commitments to refuel the C-5s.

Either Option A or Option E leaves the Air Force with significant means for managing its response to uncertainties. Option E's overriding advantage is low cost in an era of scarce resources for defense. The differences in capability and cost illustrated by Options A and E bring into sharp focus the fundamentally different missions for which military and civil-style transports are optimized. Although the military transports, especially the C-17, are designed for a large spectrum of military purposes, such flexibility comes at a high cost. The issue is whether the entire military airlift fleet should have substantial flexibility or whether a segment of the fleet should be tailored to provide low-cost delivery of some of the needed cargo. The latter approach offers the promise of a larger overall capacity for airlift given a constrained budget. The challenge for decisionmakers is to select the mix of these diverse resources that provides sufficient airlift capability for future needs at the least cost.

Finally, what if the government pursues Option E and then air carriers object to the government operating civil-style transports that may even be carrying some govern-

ment employees during peacetime? The government could offer industry a government-owned contractor-operated arrangement in which air carriers would use some of the equipment during peacetime and provide the government both the aircraft and flight crews during an emergency. Such an outcome, of course, would reduce the cost of Option E.

MAIN CONCERNS RAISED BY THIS RESEARCH

As a method for maintaining capacity and reducing costs in the strategic airlift mission area, Option E has raised a number of concerns. Most of these are discussed in Volume 3. We address three of the most important concerns here.

Assessing the Magnitude of Potential Reductions in Costs

The magnitude of potential cost reductions attributable to substituting 747s for C-17s is a matter of debate because of differences in analytic methods. To illustrate the nature and the extent of the debate, we focus on differences between our 1992 research and the DoD's 1993 C-17 Cost and Operational Effectiveness Assessment (COEA). Most of the cost difference is the result of different estimates of how many 747-400Fs would be required.

Sensitivity of 747-400F Fleet Size to Three Key Parameters. Most of the cost difference is the result of different estimates of how many 747-400Fs would be required. The difference in fleet size estimates is due mainly to different estimates for three parameters: (1) utilization rates, (2) payload, and (3) load mix. Figures 4.35 and 4.36 illustrate the effects of those differences on 747-400F fleet size, and therefore costs.

Each of the four charts in Figure 4.35 addresses a different pair of values for the utilization rates estimated for the C-17 and the 747-400F. The upper left chart is based on COEA utilization rates for each aircraft; the lower right chart is based on our estimates for each aircraft. The lower left chart is based upon our estimate for the C-17 and the COEA estimate for the 747-400F. The upper right chart is based upon the COEA estimate for the C-17 and our estimate for the 747-400F. The reader can use these four charts to interpolate results for other combinations of utilization rates.

Each chart in Figure 4.35 addresses the movement of mixes of cargo containing oversize and bulk, but no outsize. (We discuss outsize cargo later.) The heavy lines in each chart represent results based upon the COEA estimate for the C-17's payload; the light lines represent results based upon our estimates for the C-17's payload. Each set of three heavy or three light lines represents a set of load-mix conditions. The top line in each set represents the case in which less than 33 percent of the load is bulk cargo and the remainder is oversize. The middle line represents the case in which 60 percent of the load is bulk and the remainder is oversize. The bottom line is for the case in which all of the cargo is bulk.

The vertical axis for each chart shows the number of 747-400F transports required to deliver the same total tonnage as a fleet of 120 C-17s. The triangle in Figure 4.35

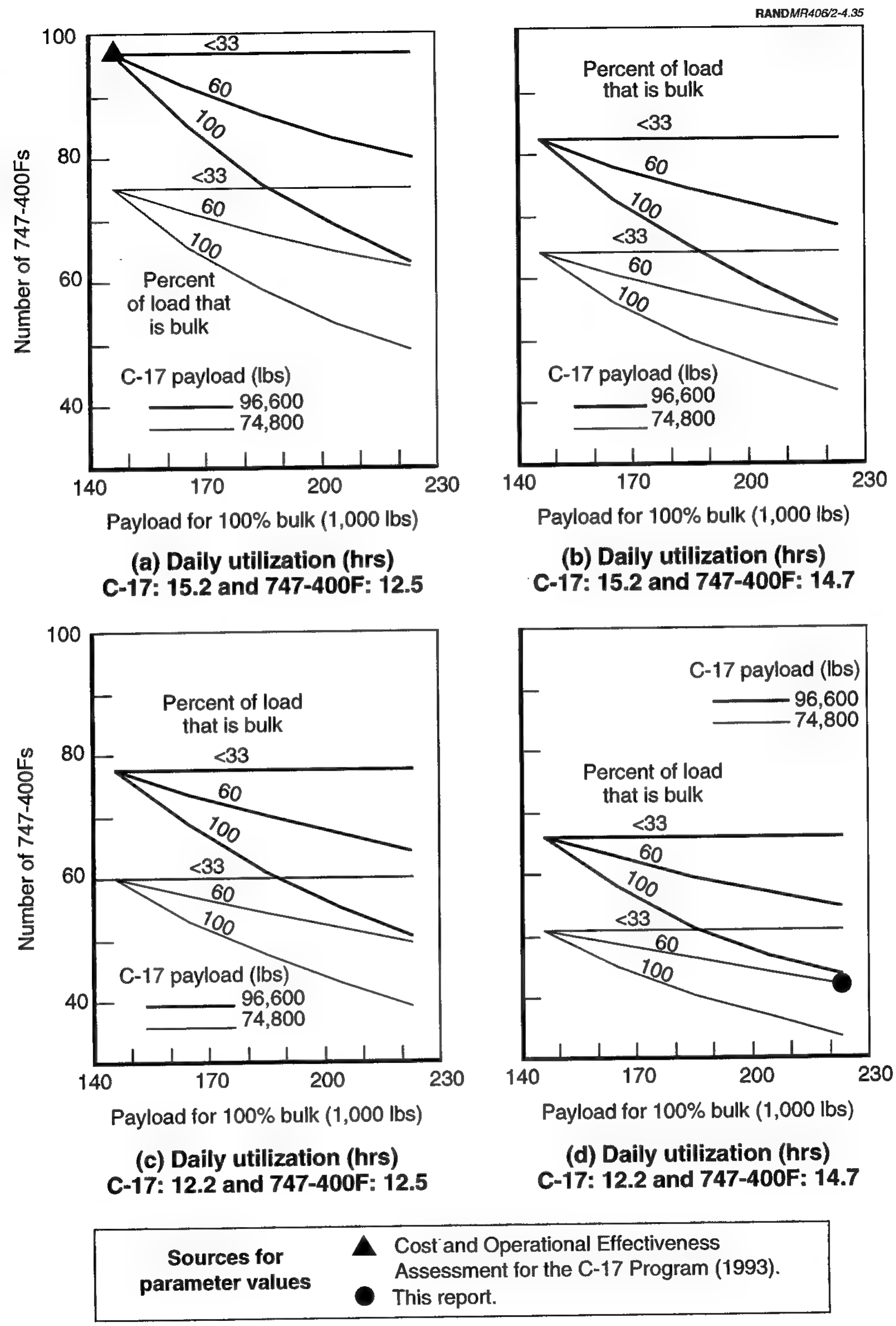

Figure 4.35—Size of 747-400F Fleet Required to Replace 120 C-17s Is Sensitive to Analysis of Utilization Rates, Payloads, and Cargo Mix

shows the number of 747-400Fs needed based upon COEA estimates for utilization rates, payloads, and load mixes, and the bullet shows our estimate. The number ranges from 97 (based upon the parameter values from the COEA) to 42 (for our estimated values).

Such a large discrepancy in estimates has a dramatic effect on the potential cost savings, as Figure 4.36 illustrates.

Utilization Rates. The COEA used Air Force planning factors for daily utilization rates. As Figure 4.35 (a) illustrates, these rates are 15.2 and 12.5 hours per day for the C-17 and the 747-400F. Our estimates (as shown in Figure 4.35 (d)) are 12.2 and 14.7 hours per day for the C-17 and the 747-400F. The reasons for these differences are explored by Topics 28 through 33 in Appendix B of Volume 3. The topics also discuss concerns that have been raised regarding our estimates. There are two main reasons why we estimated higher utilization rates for the 747-400F: (1) We estimated that it would require less time for unscheduled maintenance, and (2) we estimated that it would have to stop less often for refueling because of its greater range.

Payloads. The horizontal axis in Figure 4.35 is the estimate for the 747-400F's average payload for missions where the 747-400F is carrying a load that is 100 percent bulk cargo. The COEA's estimate for the 747-400F's average payload is 146,200 lbs for all missions. Our estimate is 145,000 lbs for oversize missions and 223,200 for bulk cargo missions.[73]

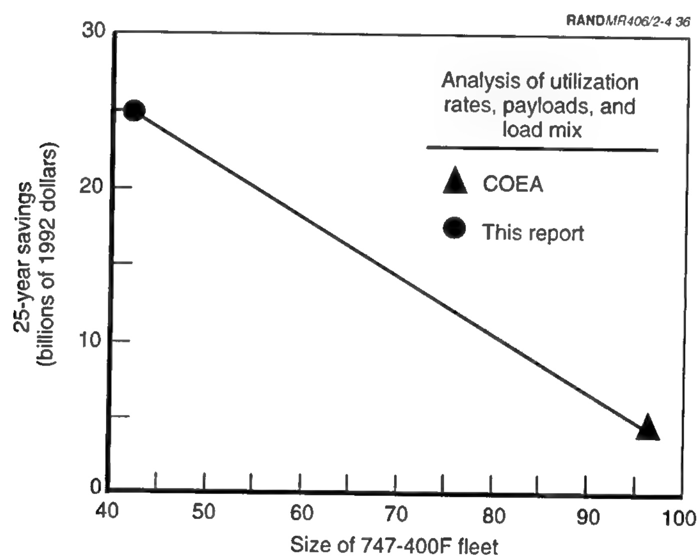

Figure 4.36—The 25-Year Savings Attributable to Buying a 747-400F Fleet Instead of 120 C-17s Is Sensitive to Analysis of Utilization Rates, Payloads, and Load Mix

[73]See Topic 27 in Appendix B of Volume 3.

The two payload values for the C-17 are our estimate (74,800 lbs) and the COEA estimate (96,600 lbs) for missions in which the C-17 is carrying either oversize or bulk cargo. In our analysis,[74] the C-17's payload was limited by cargo density considerations when carrying oversize (or outsize) to 74,800 lbs. It was limited to the same payload when carrying bulk by the aircraft's range capability. The critical leg lengths for the routes used in our analysis were representative of those experienced during the Gulf War airlift.

Our high payload estimate for the 747-400F reflects the aircraft's large volume and its long-range capability. The estimate is consistent with Air Force planning factors for bulk cargo density and assumes the use of 463L pallets. It also assumes that the height limit on pallets is 10 feet. Use of commercial pallets or commercial containers would allow for higher payloads (up to 237,000 lbs) that are within the range capability of the aircraft.

Load Mix. If less than 33 percent of the load is bulk cargo, the 747-400F's pallet positions that are best used to carry bulk-cargo pallets (lower lobe and on the main deck in the nose area and the tail area) are not used. Consequently, the curves in Figure 4.35 are flat when bulk cargo is less than 33 percent. This means that the fact that a 747-400F's payload could be greater than 145,00 lbs when carrying 100-percent bulk became a moot point in this sensitivity analysis when there was not at least 33 percent of the cargo in the form of bulk cargo.

When we accounted for differences in block speed (not accounted for in Figure 4.35),[75] our research found that a fleet of 42 747-400F transports could[76]

- deliver 45 percent more than a fleet of 120 C-17s when delivering only bulk cargo
- match the deliveries of 120 C-17s when delivering a mix of 38-percent bulk and 62-percent oversize
- deliver 82 percent as much cargo as 120 C-17s when delivering a mix of 25-percent bulk and 75-percent oversize.

As points of reference, the Gulf War airlift deliveries averaged 48-percent bulk during the first 30 days and 63-percent bulk in the peak month (January 1991).[77] However, current DoD planning calls for only 25 percent of the first 30 days' deliveries by airlift to be bulk cargo.

Of course, the 747-400F cannot carry outsize materiel, and that is why the foregoing comparisons focus on bulk and oversize. Regarding outsize, Figure 4.26 shows that 34 percent of the total capacity addressed in our analysis was outsize capable, given the 1992 fleet. That remains unchanged by replacing two-thirds of the C-141 fleet

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[74]See Topic 26 in Appendix B of Volume 3.

[75]Figure 4.35 and 4.36 do not include the effects of block speed. See Volume 3, Appendix E, for details.

[76]Using the COEA's values for block speeds would reduce the 747-400 fleet's deliveries cited above by about 10 percent.

[77]These percentages take into account outsize cargo. Excluding the outsize, the percentages become 53 percent for the first 30 days and 68 percent for the peak month.

with 747-400Fs. However, if C-17s replace the same C-141s, 60 percent of the airlift capacity is outsize capable.[78]

Magnitude of the Estimated Cost Reduction. Over the 25-year period (1993 through 2017), we found that buying and operating a fleet of 42 747-400F transports instead of continuing plans to produce 120 C-17s past fiscal year 1992 could result in savings of $25 billion (1992 dollars). The parameter values from the COEA analysis, on the other hand, suggest a much smaller potential savings. If block speed differences are not considered, the savings could be as small as $5 billion (Figure 4.36). Even if they are considered, the savings would still be as low as $6 billion to $8 billion, depending upon how block speed differences are analyzed. See Appendix E of Volume 3 for further discussion of the differences in parameter values.

As already discussed, over the 25-year period (1993 through 2017), we found that buying and operating a fleet of 42 747-400F transports, instead of continuing the acquistion of 120 C-17s past fiscal year 1992, could result in savings of $25 billion (1992 dollars).[79] The parameter values from the COEA analysis, on the other hand, suggest a much smaller potential savings. If block speed differences are not considered, the savings could be as small as $5 billion (Figure 4.36). Even if they are considered, the savings would still be as low as $6 billion to $8 billion, depending upon how block speed differences are analyzed. See Appendix E of Volume 3 for further discussion of the differences in parameter values.

Loss of Flexibility: An Operational Concern

The present strategic airlift system is already fairly flexible and complemented by a tactical airlift system of significant size and capacity. However, retirement of the entire C-141 fleet will reduce strategic airlift capacity operated by the DoD by almost half. The need to replace C-141s raises important trade-offs among costs, total capacity, and flexibility. If the cost of equal or greater flexibility means less capacity in the end, is that the right choice? If, on the other hand, we must trade current levels of flexibility to maintain current capacity, is the residual flexibility sufficient to satisfy future needs?

An important effect of implementing Option E would be a decrease in the operational flexibility that only the military-style transport can provide. As discussed in Chapter One, this flexibility includes (1) the ability to use airfields with no preexisting infrastructure, (2) the ability to carry large items of equipment, (3) ease of loading vehicles, (4) the ability to air drop personnel and materiel, (5) the ability to minimize exposure to threats through low-level flight and through rapid offloads on runways, and (6) aircraft system designs that are damage tolerant. The DoD would also forgo capabilities unique to the C-17, such as the abilities to (1) use short

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[78]If one assumes that the current CRAF Stage II (twice the size of the 1992 Stage II fleet) is activated, the portion of the fleet that is outsize capable is 47 percent. For a Stage III activation, the percentage falls to 37 percent.

[79]Production of the C-17 did continue past 1992, and, thus, the current potential savings is less. As of late 1994, the potential savings are about $20 billion in 1994 dollars.

runways,[80] (2) deliver outsize materiel to short runways, (3) park in small areas, (4) maneuver in close quarters, and (5) back up on inclined surfaces. Unlike the 747, the C-17 can move all classes of cargo and deliver loads directly to austere airfields.

Retirement of the Entire C-141 Fleet Changes the Decision Context

Since completion of the research in 1992, the DoD has decided to retire the entire C-141 fleet by the year 2005. This action has created a new airlift investment decision that is different from the one we examined. The capabilities lost by the retirement of the last third of the C-141 fleet will need to be replaced by either the C-17[81] or some other military-style transport(s), such as the C-5 or possibly the C-130, although the C-130 flies slower and not as far as the C-17. The number and type of aircraft needed to replace the final third of the C-141 fleet, and therefore the cost estimate for the investment, will depend upon the key parameters at the heart of all airlift analyses: estimates for payloads, utilization rates, block speeds, load mixes, and level of CRAF participation. Thus, our analyses of the right mix of military and civil airlift given 1992 conditions can be improved in two ways: (1) by examining alternatives for replacing the needed capabilities lost with the planned retirement of the entire C-141 fleet, and (2) by analyzing and clarifying the uncertainties in the key parameters.

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[80]The extent to which the C-17 can use short runways is uncertain, as is discussed in Chapter Five.

[81]The number of C-17s required to replace the entire C-141 fleet is sensitive to estimates for payloads, utilization rates, block speeds, and load mix. See Appendix F of Volume 3.

Chapter Five

AIRFIELD ACCESS IS A MAJOR FLEET-COMPOSITION ISSUE

Improving access to austere airfields, to reinforce NATO's frontline units quickly, was a primary requirement driving the conceptual design of the C-17 aircraft. Today, the issue of how well the C-17 can actually achieve such a goal is a major consideration that affects two fleet-composition issues. First, to what extent would the C-17 play a unique role in accessing airfields? Second, in view of the capabilities of the C-17 to use austere airfields, should the C-130 production line be closed?

To address these questions, this chapter briefly examines the factors influencing airfield access and then focuses on runway characteristics, because the alternative transports place different demands on a runway's size, strength, and durability. These different demands have significant implications for the ability of the transports to use the world's airfields. The main variables in this discussion are the requirements for lengths and widths of runways and the stresses that the transports place on the runways. A significant part of this chapter provides background material on the nature and implications of runway stresses. It then draws upon that background to examine the airfield-access question in two parts. The first part considers the case in which using aircraft do not overstress runways. The second part examines the case where accelerated wear of runways is allowed during an emergency, and, consequently, the transports are permitted to conduct operations that overstress the runways. The chapter closes by considering the implications of shutting down the C-130 production line. Figure 5.1 provides a roadmap for this discussion.

AIRFIELD ACCESS DEPENDS UPON MANY CONSIDERATIONS

The suitability of an airfield to support major airlift operations depends upon many factors, including political considerations and physical suitability.

Political Considerations Affect All Aircraft

Political considerations refer to the willingness of foreign countries to allow long-term or even short-term use of their airfields. Such willingness may be influenced by a wide variety of domestic and international considerations. For example, how would such use affect the operations of their own military and/or civil air carriers?

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Airfield Access Is a Major Fleet-Composition Issue

1. Airfield access depends upon many considerations:
   - Political considerations affect all aircraft.
   - Physical suitability varies by type of aircraft.

2. C-17 places higher stresses on runways than either a C-5 or a C-130:

   Background

   - Many factors contribute to runway stress.
   - Designs of both the runway and the landing gear affect amount of stress on runways.
   - High stress levels can cause failure of a runway.

   Problem

   - Assessments of runway stresses and durability have been flawed.

   Analysis

   - Two approaches are used to assess stresses and airfield access.
   - Two landing conditions are relevant to assessing runway stress and airfield access.
   - Basic factors show a C-17 places the most stress on runways for both landing conditions.
   - U. S. Army Corps of Engineers assessed runway stresses caused by transports.
   - RAND confirmed Corps of Engineers comparative assessment of stress levels.

3. C-17 and C-5 have comparable access when runways are not overstressed:
   - Analysis of U.S. airfields shows comparable access for a C-5 and a C-17.
   - Analysis of foreign airfields confirms comparable access for a C-5 and a C-17.

4. Whether a C-17 has more access to overstressed runways than a C-5 is an issue:
   - LCN 20 concrete runway would crack the first time a C-17 used it.
   - LCN 20 asphalt runways last longer with a C-5 or a C-130 than a C-17.
   - Operating on runways down to LCN 20 would increase airfield access.

5. The C-130 remains a uniquely important resource:
   - The C-130 has greater access to paved runways than a C-17.
   - The C-130 has greater access to unpaved runways than a C-17.
   - Upgrading the C-130 design would increase its access to airfields.

6. C-17's access to airfields is more limited than previously envisioned.

Figure 5.1—Flowchart for Chapter Five

How would such use affect people living in the neighborhood of such airfields? For example, during the Gulf War airlift, night operations were not allowed at one German airfield because of noise considerations. Although the many factors influencing political suitability lie beyond the scope of this research, they nonetheless are important variables in the airfield access equation. They, however, tend to affect all aircraft equally.[1]

Physical Suitability Varies by Type of Aircraft

Physical suitability, on the other hand, depends strongly on the characteristics of both the airfield and the aircraft using the airfield. The previous chapter analyzed alternative fleets in terms of two factors influencing physical suitability of airfields:

- **Fuel.** Availability and allocation of fuel can limit access to an airfield. Moreover, military transports require a different type of fuel (JP-4) than civil transports (Jet A). Availability of fuel for transport aircraft can be constrained by competing users, such as combat aircraft. It can also be constrained by storage capacity, amount on hand at the start of an airlift, daily capacity to replenish airfield fuel supplies, and capacity of airfield fueling systems to refuel aircraft. Fuel availability for transport aircraft was one of the factors limiting throughput during the Gulf War airlift.
- **Ramp space.** Availability and allocation of appropriately paved surfaces for parking transports can limit access to an airfield. Parking surfaces must be of sufficient size, strength, and durability to accommodate the size, turning requirements, and weight-bearing characteristics of transport aircraft. Allocation can be influenced by competing users, such as combat aircraft. Availability and allocation may have limited airlift throughput during the Gulf War.

The main technical consideration examined in this chapter is:

- **Runways.** Access to an airfield can be limited by one of many runway characteristics: length, width, pavement thickness, subgrade thickness, and technical characteristics of the pavement material; the subgrade material underlying the pavement; and the natural soil underlying the subgrade material. Whether access is limited also depends upon the weight-distribution characteristics of the aircraft.

Other physical factors considered in our research include taxiways, airfield altitudes, and temperature ranges at airfields. Figure 5.2 compares the taxiway and ramp needs for the transports of interest to this research. Additional factors affecting airfield suitability include obstacles in the vicinity of runways, taxiways, and ramps; ground support services; and support equipment. AMC evaluates all of these factors, and related considerations, when it evaluates the suitability of airfields for use by its transports. This information is maintained in the Airfield Suitability Report database

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[1]A possible exception is the 747-400, which may need fewer en route stops for refueling, depending upon the deployment distances.

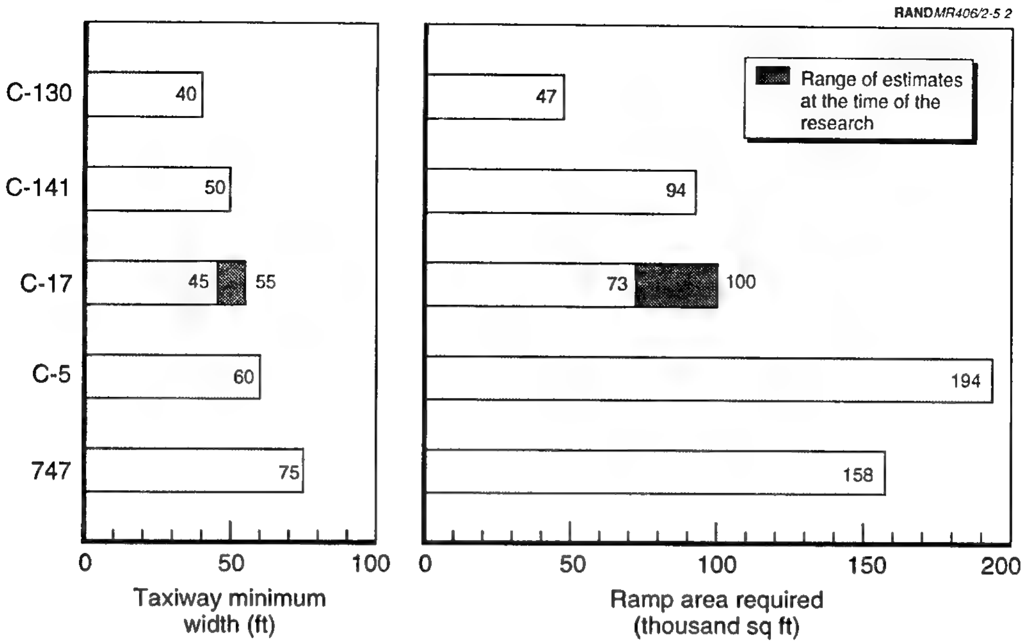

Figure 5.2—Big Aircraft Need Wide Taxiways and Large Ramps

that was used to support part of our analysis. During 1992, the database included assessments for 830 airfields in the United States and 1,718 foreign airfields.

Although there is no question that the C-17 can use runways smaller than those required by the C-5, C-141, and 747, there is an issue regarding runway-strength requirements for all these aircraft and for the C-130.

Whether the C-17 can access more airfields than the C-5 and whether it can access as many as the C-130 centers mainly on how rapidly these aircraft consume the available useful life of runways. To analyze this situation, three research questions were addressed. What are the relative stresses that these aircraft place on runways? Does the C-17's advantage in using smaller runways more than offset the C-5's advantage in imposing lower stresses on runways? Can the C-17 match the C-130's access to airfields?

A C-17 PLACES HIGHER STRESSES ON RUNWAYS THAN EITHER A C-5 OR A C-130

The transports of interest to this research place significantly different levels of stress on runways. These stresses make a significant difference when using weaker runways, many of which happen to be small and accessible only by a few types of transports. The issue of runway stress is significant, because, although the C-17 has advantages in using small runways, it imposes greater stresses than the C-5 and the

C-130. To lay the foundation for examining the nature and significance of these greater stresses, we will review the

- factors that influence stress levels in runways
- consequences of high stresses and methods for managing stress levels
- flaws in past assessments of stress levels and runway durability.

We then will analyze the stress levels created by different transports. The analysis has three parts:

- Identification of two landing conditions relevant to a comparative analysis of transport aircraft in terms of the stresses they create in runways and the implications of repeated application of such stresses on a runway's durability and hence the possibility of airfield access
- Basic factors that show why the C-17 places greater stresses on runways
- Assessments of stress levels by the U.S. Army Corps of Engineers and RAND.

Many Factors Contribute to Runway Stress

The stresses that an aircraft places on a runway affect the ability of that aircraft to use the runway for recurring operations. Runway stress depends upon the following:

- The runway's capability to
  - — Bear the weight of the aircraft without suffering damage or accelerated wear of the pavement, the subgrade, and the natural soil underlying the subgrade
  - — Degrade gracefully under operations that cause accelerated wear
- The aircraft's operating weight and its weight distribution characteristics
- The airfield operator's
  - — Willingness to accept operations that overstress the runway and cause accelerated wear
  - — Ability to repair the runway without shutting down airlift operations for unacceptably long periods of time; this depends upon
    - The airfield operator's ability to obtain delivery of any additional personnel, equipment, and materiel needed to repair runway pavements and subgrades
    - The theater commander's willingness to accept interruption of airlift operations to allow time for repair of runway pavements and subgrades.

The Designs of Both the Runway and the Landing Gear Affect the Amount of Stress on the Runway

When an aircraft lands or takes off, the stresses on the runway are determined by its weight-bearing capability and the weight-bearing characteristics of the main landing gear, which supports 90 to 95 percent of the aircraft's weight. A runway with a very

high weight-bearing capability might have a thick concrete pavement laid on top of a strong subgrade constructed from layers of gravel and sand, which rest in turn on compacted soil that overlays a naturally strong underlying soil. A heavy transport with low stress characteristics might have a large number of wheels that distribute the weight of the aircraft over a large area of the runway. When such an aircraft uses the described runway, the concrete pavement would bend slightly, thereby distributing the aircraft's loads over an even larger area of the subgrade. The subgrade would further spread the loads that the underlying natural soil would have to support. In this example, the stresses created in each layer of the runway would be relatively small, and very little of the runway's useful life would be consumed by that one use.

Runways Reactions and Stress Levels Depend upon the Type of Runway. Because a runway's reaction to an aircraft depends upon the type of design, runways have been divided into three broad categories:

- **Unpaved.** Such runways lack a surface that remains firm under all weather conditions. Unpaved runways include grass landing strips, as well as dirt and sand strips. They also include gravel landing strips.
- **Rigid pavement.** Runways with concrete pavements are classified as rigid, provided that the concrete is mostly intact (minimum amount of through cracking has occurred) and the pavement thickness is mostly concrete. Such a pavement will react like a beam to distribute the loads imposed by an aircraft. The pavement in a broad area around each wheel will participate in the runway's reaction to the loads imposed by that wheel (Figure 5.3). This broad participation of the neighboring pavement serves to spread the tensile stresses and minimize the maximum tensile stress that the pavement must endure.
- **Flexible pavement.** Runways with an asphalt-like pavement are classified as flexible. Such a pavement will react only in a local area around each wheel (Figure 5.3), assuming that the underlying subgrade and soil do not fail. Asphalt, unlike concrete, does not transmit bending loads through the neighboring pavement.

To simplify the analysis and discussion, we adopted a simple model for a paved runway that masks the complexities of actually designing and maintaining real runways. For example, real runways have many layers of materials that are designed to distribute aircraft loads in a way that allows the natural soil underlying the runway to support the imposed loads without deformations that are unacceptably large and permanent. We model these layers of material as illustrated in Figure 5.3. The uncompacted natural soil is the material that was in place at the time the runway was constructed.[2] The pavement is the top layer of material (concrete or asphalt). All

[2]See Portland Cement Association (1992) and U.S. Department of Defense (1964) for an introduction to soils and the testing of soils pertinent to runway design and construction.

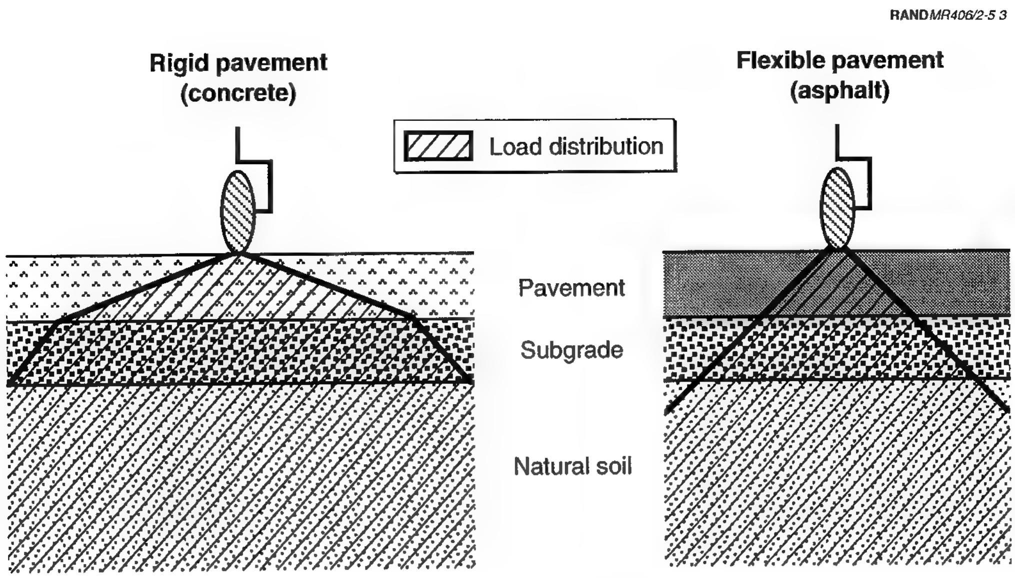

Figure 5.3—Concrete and Asphalt Pavements Distribute Loads Differently

layers between the pavement and the underlying, undisturbed natural soil are what we will call the subgrade.[3]

Runway Reactions and Stress Levels Depend on Landing-Gear Design and Aircraft Weight. A runway's reaction to an aircraft also depends upon the landing-gear design and the weight of the aircraft. Landing gears have been classified as follows:

- **Single wheel.** An aircraft with only a single main landing-gear wheel on each side of the fuselage is classified as a single-wheel gear, because the wheels on either side of the fuselage are so far apart that the runway reaction remains limited to the local area of each wheel.
- **Multiple wheel.** An aircraft with more than one wheel on each side of the fuselage has a multiple-wheel landing gear, unless the wheels are spaced so far apart that each has its own set of landing-gear hardware and the runway's reaction is limited to the local area of each wheel. The transport aircraft of interest to this study have multiple-wheel landing gears.[4]

For multiple-wheel landing gears, it is important to consider the combined loads of all the wheels in assessing reactions of runways to specific aircraft. It is also important to find the point on the runway surface where the runway has the greatest reaction to the combined effect of all the wheels. The greatest tensile stress will occur at

[3]Various nomenclatures are used in the literature for rigid and flexible runways. Some reports refer to the undisturbed natural soil as the subgrade. Others refer to compacted or otherwise treated natural soil as a subgrade.

[4]See Turnbull, Foster, and Ahlvin (1955) for early work on designing flexible airfield pavements for multiple-wheel landing-gear assemblies.

some depth under the point on the surface where the runway experiences the greatest reaction (i.e., deformation).

High Stress Levels Can Cause Failure of a Runway

A runway with low weight-bearing capability might have a thin layer of asphalt overlying a thin subgrade of gravel or other material lying on top of an uncompacted natural soil that is fairly weak in terms of its ability to bear loads without significant permanent deformation. A heavy transport with high stress characteristics might have a few closely spaced wheels that distribute the aircraft's weight over a small area of the runway. If such an aircraft were to use the described runway, the concentrated loads of the aircraft would be transmitted quickly to the underlying soil because of the thinness of the overlying pavement and subgrade, and because asphalt does not bend and distribute loads as does concrete. The underlying natural soil would find the stresses created by the loads too great to withstand without significant permanent deformation. Soil under the landing gear would be displaced toward the sides of the runway and the overlying subgrade and pavement would sink, leaving a permanent rut where the landing gear's wheels had passed. If the tires on the landing gear were high in pressure, the ruts would be even deeper. If the ruts from this single use are deep enough, they could render the runway unsafe: The rough runway could stress the next aircraft's landing gear enough to cause critical parts to fail, potentially leading to its collapse. The result might be uncontrollable and could jeopardize the aircraft and its occupants.

The LCN Reflects Runway Reaction and Maximum Stress Levels. To avoid both catastrophic failure and premature wear-out of runways, an empirical scheme was devised by the British during World War II and has since evolved to provide a standard systematic approach for calculating load classification numbers (LCNs) that reflect runway reactions and their maximum stresses when used by specific aircraft. The LCN assigned to an aircraft is dependent upon the aircraft's characteristics (operating weight and weight distribution), as well as the assumed characteristics of the runway that is used in calculating the aircraft's LCN. This system has helped

- airfield operators design and manage the development, maintenance, and use of their runways
- aircraft manufacturers design the landing gear for their aircraft
- aircraft operators understand the basis upon which operators of specific airfields could be expected to
  - Place limitations on the gross operating weight of an aircraft using a runway at that airfield and the maximum frequency with which such aircraft may use the airfield
  - Assess surcharges to landing fees to compensate for accelerated wear of a runway when aircraft land at weights too great for the runway's designed service life.

At the heart of the LCN scheme is the basic concept that ***if two aircraft cause the same maximum stress on a runway as the runway reacts to the aircraft, the calculated value for the LCN should be the same.*** Although the LCN concept has a certain elegance in its simplicity, two factors complicate implementation of the concept. First, each combination of runway design and aircraft landing-gear design presents a different mechanical system. Second, there are a wide variety of different types of runways and aircraft landing gears.[5] Because runway reactions vary depending upon the type of construction, different types of factors must be used to calculate the LCN for different types of runways, as illustrated in Table 5.1.

Rules for Calculating LCN Are Different for Rigid and Flexible Runways. The rules for calculating LCN differ for each type of runway because the nature of the runway's reaction is fundamentally different for each type:

- **Rigid pavement runways.** Because a concrete pavement has a beam-like reaction that distributes the loads imposed by the aircraft over a broad area, the failure mode of primary interest is a general cracking of the pavement that destroys this beam-like capability to distribute loads. Because a cracking failure of such a pavement is likely to originate at the interface between the pavement and the subgrade where the tensile stresses are greatest, the value of LCN is calculated at that interface (Figure 5.4).[6] Technically, the pavement is in a state of tension at this interface.

- **Flexible pavement runways.** For these runways, the flexible pavement provides a weatherproof surface over the subgrade. Loads are distributed through the

Table 5.1

Different Factors Are Used in Calculating Aircraft LCN for Concrete and Asphalt Pavements

Factors	Rigid (concrete)	Flexible (asphalt)
Tire pressure	X	X
Load carried by each wheel	X	X
Arrangement of wheels	X	X
Thickness		
Pavement	X	
Pavement plus subgrade		X
Elasticity of pavement	X	
Supporting material		
Reaction modulus at top of subgrade	X	
CBR at top of natural soil		X

[5]See U.S. Department of Transportation (1978) for a discussion of airport pavement design and evaluation and the many factors that enter into the design and operation of a runway.

[6]Concrete is better at withstanding compression stresses than tension. See Ahlvin et al. (1971) for descriptions of the failure modes encountered in the multiple-wheel heavy-gear-load pavement tests conducted by the U.S. Army Waterways Experiment Station. Also see Yoder and Witczak (1975), Chapter 18.

pavement in the same manner as they are distributed through the subgrade. Notice that the slope of the load distribution line in Figure 5.4 does not change in passing from the pavement to the subgrade for the flexible pavement case. Two failure modes are of primary concern: The first is cracking of the pavement that allows moisture into the subgrade and weakens the ability of the subgrade and the underlying natural soil to withstand loads. The second is failure of the natural soil underlying the subgrade to react to aircraft usage without unacceptably large permanent deflection.[7] Large permanent deflections of the natural soil at the interface with the subgrade will be reflected in permanent deformations of the overlying subgrade and pavement. Because the interface between the subgrade and the natural soil is a major point of concern in terms of the origination of failures for flexible runways, the LCN is calculated at that interface (Figure 5.4).

Assessments of Runway Stresses and Durability Have Been Flawed

Past comparisons of the relative capabilities of military transports to use runways need to be reexamined. Past assessments of the stresses that military-style transports cause in runways (as calculated in terms of LCN) have been flawed because the application of the LCN concept to Defense Department aircraft has lacked management discipline. This has been confounded by the fact that assessments of stresses (as calculated in terms of LCN) are based upon approximations for the behavior of

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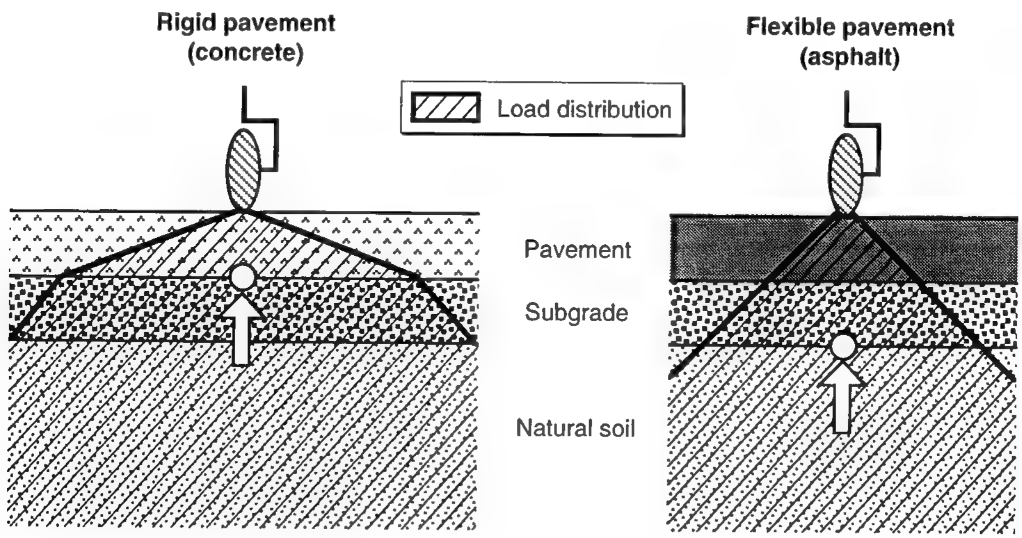


NOTE: LCN = f(tire pressure, deflection of runway at point ○); point ○ is defined differently for concrete and asphalt runways.

Figure 5.4—LCN Calculation Is Made at Different Points for Concrete and Asphalt

[7]See Yoder and Witczak (1975, Chapter 18) and Ahlvin et al. (1971) for descriptions of failure modes.

runways when they are subjected to heavy loads. Moreover, the approximations require several assumptions to characterize the runway being used to calculate the aircraft's LCN values for different operating weights. We first review the nature of the approximations and we then address the lack of management discipline.

Assessments Are Based upon Approximations. The LCN system, and other related systems, such as the aircraft classification number (ACN) system discussed later, are schemes that are used to provide approximations for the complex interaction that occurs when an aircraft uses a runway. The system has limitations:

- **The methods are empirical and only provide approximations for the reactions of runways and their maximum stress levels.** Lacking scientific theories for precisely modeling the reaction of pavements, subgrades, and soils, engineers have devised empirical methods that provide tools for design and evaluation.[8] The tools are based upon plausible concepts for approximating the mechanics of how material systems react. They are calibrated by using observations from special tests and actual operational experience of runways and other pavements, such as roads. Generally, modern tools are fairly good. They nonetheless have imperfections that are a source of imprecision.[9]
- **Multiple wheels contribute to lack of precision.** As the number of wheels on large aircraft have increased, the technical complexity of modeling runway reactions has increased and the lack of scientific precision has become more problematic, in part due to the limited research that has occurred in recent decades (see Hammitt, Hutchinson, and Rice, 1971).
- **Incomplete information about runway construction limits ability to assess runway reactions and stresses.** Some of the most serious limitations stem from incomplete knowledge about specific runways: (1) their design and (2) the properties of the materials used in their construction. These problems are made worse by the great variety of runway designs and subgrade conditions that, in combination, affect the runway's reaction characteristics. Almost every runway has a unique set of technical characteristics that influence its reaction to aircraft loads. Moreover, reactions will vary depending upon the loads and design of the landing gear.
- **Gaps in scientific knowledge about the effect of repeated loads are a source of imprecision.** The science of understanding the cumulative effects of cyclic loading of material systems has made great strides during the past century. Much additional work remains to be accomplished, however, before we can predict with precision how and when material systems will fail under repeated loads. Until then, we are left with engineering approaches that attempt to capture what science knows of failure phenomena, while filling in the gaps with rea-

[8]For early work investigating the pressures and deflections for soils and subgrades, see U.S. Army Corps of Engineers (1951) and Sowers and Vesic (1962).

[9]For the development of early methods based upon the California Bearing Ratio, see American Society of Civil Engineers (1950) and Turnbull (1956). The most significant runway reaction experiment, conducted by the U.S. Army Corps of Engineers, evaluated and recalibrated some of the methods during the early 1970s; see Ahlvin et al. (1971) and Hammitt, Hutchinson, and Rice (1971).

sonable empirical methods. Although the science and engineering of dealing with the durability of aircraft structures have made impressive progress in recent decades, thanks to significant research efforts, such is not the case for runways of interest to military airlift operations. A major part of the problem is our limited knowledge of the failure physics for runways, especially under conditions of wartime airlift operation, in which old runways may be pushed further and harder than during peacetime use. Another big part of the problem of understanding runway durability is that we lack accurate information about the runways of interest. The technical factors listed in Table 5.1 are rarely known for runways at foreign airfields.

Application of the LCN Concept to DoD Aircraft Has Lacked Management Discipline. There is a further source of difficulty that comes from how the DoD has managed its application of the LCN concept to DoD aircraft and to airfields of interest to the DoD. The apparent lack of management discipline that we found might be excused on the basis that the LCN concept and its application are only approximations. However, major resource investment decisions are being made on the basis of LCN information. There are three concerns:

- **Important assumptions are not managed and usually go unmentioned.** To calculate an LCN for a runway's reaction to an aircraft, certain assumptions must be made about the aircraft's operating conditions (tire pressure and gross weight) and the design of the runway (pavement and subgrade parameters listed in Table 5.1). Although the assumed values for the runway factors have a significant influence on the LCN calculated, they seem to go unmentioned. In our research, we have failed to find them specified by either contractors or the government. This creates a major ambiguity about what the weight distribution characteristics of a particular aircraft's design are supposed to be.
- **The Defense Mapping Agency (DMA) has lacked knowledge and control of its airfield assessment process.** The DMA has a responsibility to assess the suitability of foreign airfields for the potential use of the various departments and agencies of the DoD. In assigning an LCN to a runway, the DMA's staff tries to assess the probable characteristics of the runway by examining the runway and its current use. The DMA has provided written instructions to its field staff and has shared these instructions with its consumers to provide consistency to the assessment process and to provide a basis for interpreting the LCN information. However, at various levels within the DMA, we encountered widely divergent explanations for how the assessments had really been performed in the field.
  - One view was that the LCN that was assigned was a short-term rating. A runway could be expected to support about one month's worth of heavy use (say 300 missions) by airplanes with LCNs as high as the value DMA had assigned to the airfield. Beyond that point, it was likely that the runway would become unusable without significant maintenance of the pavement and possibly the subgrade.[10]

[10]See Defense Mapping Agency (1986, Enclosure 7, paragraph 2.b).

— An alternative view was that the DMA's ratings were long-term ratings, say ten years of operation could be supported by aircraft with LCNs as high as the value assigned to the runway.

The difference in these views is equivalent to about 20 points on the LCN scale for the airfields of interest to airlift operations.

- **Excessive reliance on contractor assessments in the case of the C-17 program.** Several years ago, AMC adopted a policy of intending to operate the C-17 on runways with DMA ratings as low as LCN 20, making repairs as necessary to sustain such operations. The belief that the C-17 could be used on such runways was based on an analysis by the contractor. Apparently, an independent analysis had not been performed, nor has the test program been modified to include tests on LCN 20 runways to demonstrate such a capability.[11] However, airfield-access statistics provided by the Air Force have relied on such a capability.[12]

Two Approaches Are Used To Assess Stresses and Airfield Access

The Air Mobility Command has used two approaches to assess comparative stresses and comparative abilities of aircraft to use runways and airfields. For operational purposes, it tends to use the LCN approach to grade runways at airfields. For investment-planning purposes, it has tended to use a broader-brush approach that groups LCN values into Landing Classification Groups (LCGs). For example, LCG IV includes runways to which the DMA has assigned LCN values of 31 through 50. Due to the technical uncertainty of its assessments, DMA has advised the users of its assessments that making distinctions between runways within an LCG group may be unwarranted.

In reviewing AMC's application of the LCG approach, we became concerned that AMC may be losing sight of some important and technically valid distinctions about differences among aircraft and among types of runways. Thus, we choose to use the LCN approach. (See Volume 3, Appendix C, for further discussion of the two approaches.)

Two Landing Conditions Are Relevant to Assessing Stresses and Airfield Access

To analyze the comparative capabilities of aircraft to access airfields, mission conditions must be specified to set the aircraft weights used to determine runway reactions and maximum stress levels (as reflected in LCN values). The LCN values are

[11]We do not advocate testing at this time on an LCN 20 runway, because our analysis suggests that such a test risks potential catastrophic failure of the runway with unknown consequences for the structural integrity of the landing gear. Engineering analysis and independent review should occur before a C-17 is subjected to low LCN testing.

[12]U.S. Air Force (1991) reported that the C-17 could access 10,000 airfields. Other Air Force analyses during 1988 and 1992 reported about 4,000 airfields as accessible by the C-17.

then used to search for airfields with suitable runways. Two main mission conditions are of interest:

- **Deliveries to austere airfields.** Delivery of materiel and people to austere airfields lies at the heart of addressing two questions: the C-17's role in the military airlift fleet and whether C-130 production should continue. For deliveries to austere airfields, we found the greatest stresses occurring during landing. The landing weights for the transports were assumed to be about 80 percent of the maximum takeoff weights.[13]
- **Deliveries to major APODs.** Deliveries to airfields with the infrastructure for refueling transports result in landing weights that are about 65 percent of the aircraft's maximum takeoff weights.

Deliveries to Austere Airfields Create the Highest Stresses. The main airfield-access issue is whether the C-17's short-field takeoff and landing capabilities give it the ability to access a significant number of airfields that otherwise could not be used for intertheater airlift operations. It seems reasonable to assume that fuel would not be available at an austere APOD (Figure 5.5). Thus, arriving aircraft must have sufficient fuel on board to fly to the refueling point. The need to land with such fuel on board at an austere APOD means the landing weight of the aircraft will be greater than that for deliveries to APODs where refueling is possible.

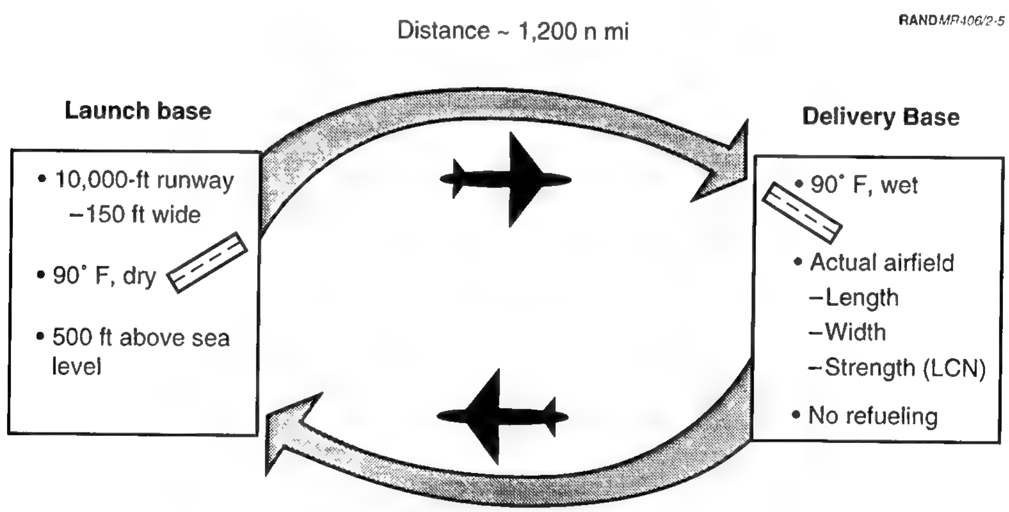


Figure 5.5—A Scenario for Deliveries to an Austere Airfield

[13]We examined a variety of scenarios for such operations and found that landing weights were approximately 80 percent of each transport's maximum takeoff weight for representative deployment loads in the situation where transports must fly up to 1,200 n mi after delivering their load before they can refuel. If transports can refuel at the delivery base, the landing weights fall to about 65 percent of the transport's maximum takeoff weight.

For the direct deliveries to austere APODs, we estimated individual aircraft landing weights and runway-length requirements by assessing their performance in a direct-delivery scenario. To illustrate the C-17's unique capabilities for landing and takeoff at an austere APOD, we assumed fairly demanding weather conditions of a wet runway and tropical temperatures (90°). For the en route refueling base, we took care not to select either a distance between bases or weather conditions that would limit the payload delivery capability of the C-17. We assumed 1,200 n mi between the bases, tropical temperatures (90°), and a 10,000-ft runway. Distances greater than that would cause the C-17's payload to drop below planning-factor levels. The length and temperature limitations only reduced the payload for the 747-400 (Figure 5.6).

The resulting range-limited payloads (Figure 5.6) for the intertheater military transports were somewhat greater than the deckload-limited payloads (Figure 4.18). The deckload-limited payloads ended up constraining the mission payloads in the throughput analysis, which was conducted after we had completed the airfield-access analysis. For the payloads in Figure 5.6 and the scenario conditions, the resulting field-length requirements at the austere APOD are summarized in Figure 5.7. The landing weights for the individual transports were between 80 and 82 percent of each transport's maximum allowable gross weight for takeoff.

Deliveries to Major APODs Can Impose the Lowest Loads on Runways. For the types of airlift missions considered in Chapter Four, the average landing weights for the aircraft of interest were about 65 percent of the maximum takeoff weights. Because only reserve fuel and payload are on board for landing, this type of mission

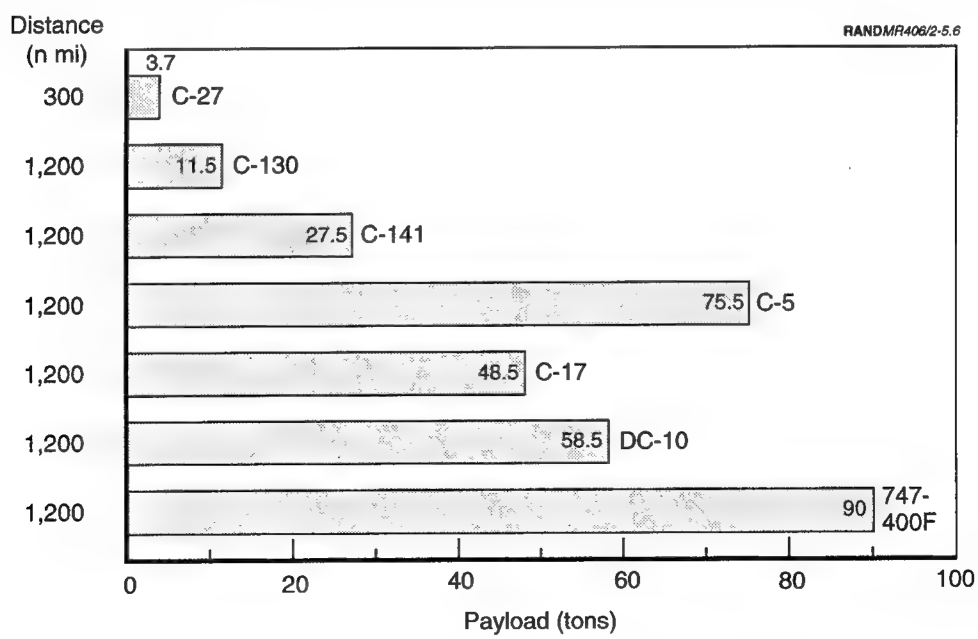


Figure 5.6—Distance and Payload for Radius Missions

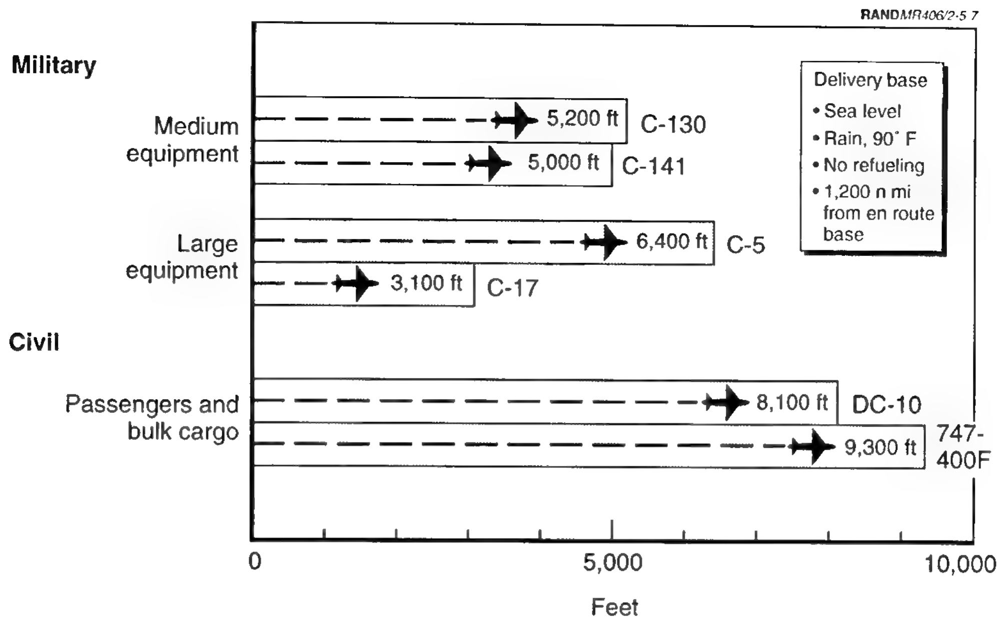


Figure 5.7—Military Transports Can Use Shorter Runways

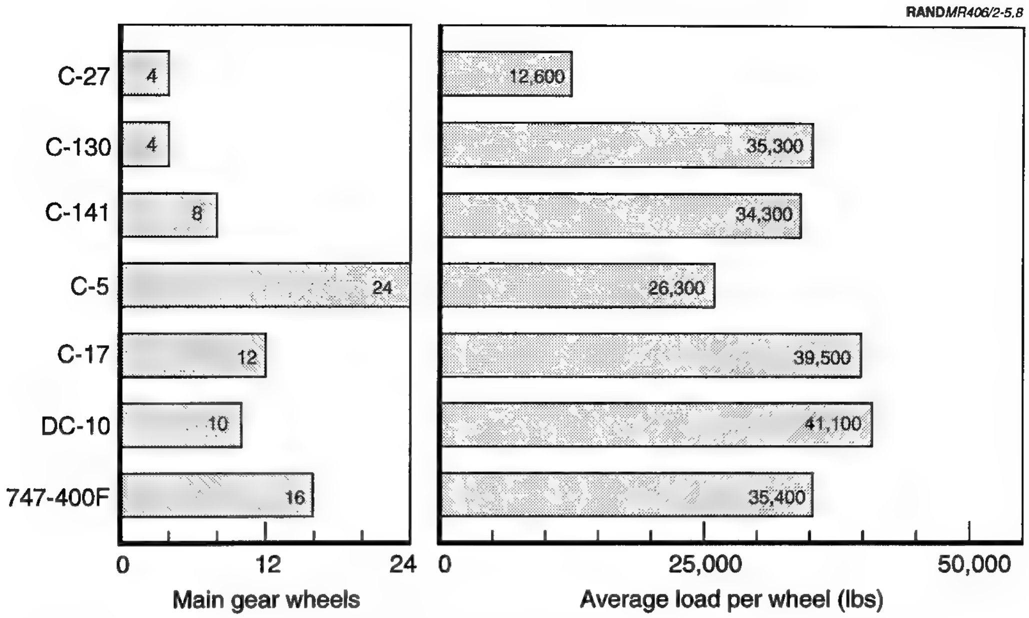
imposes the lowest landing loads on the runway at APODs. For such missions, the landing loads are of principal interest if the transports are only partially refueled. Otherwise, the takeoff loads are of principal interest, because a fully refueled transport has a higher weight, even with no payload, than the transport when it lands. Thus, if runway life became the binding constraint at a major APOD with refueling capability for the transports, partial refueling could be performed to maintain takeoff weights no greater than the landing weights.

Basic Factors Show the C-17 Placing the Most Stress on Runways for Both Landing Conditions

The Wheel Loads and Pattern of the C-17 Create More Runway Stress. The reaction of a runway to the loads imposed by different aircraft depends upon the average load supported by each wheel on the main landing gear, the tire pressure, and the wheel pattern.

- **Average wheel loads.** Average wheel loads in Figure 5.8 were calculated by dividing aircraft gross weight by the number of wheels on the main landing gear. The aircraft gross weights we used were representative of a landing weight for an airfield where cargo would be delivered but fuel would not be available. The landing weights were about 80 percent of each aircraft's maximum takeoff gross weight.

The C-17's average wheel loads are significantly higher than any other military transport, because it only has 12 wheels on its main landing gear. Although the C-17's op-



NOTES: Runway at delivery base. Average wheel weight = (landing gross weight)/ (number of wheels on main landing gear).

Figure 5.8—Wheel Loads for Main Landing Gears

erating weight is typically about three-fourths that of the C-5 for comparable operating conditions, it only has half as many wheels. Thus, the C-17's average wheel loads are 50 percent higher than those of the C-5.

- **Tire pressure.** The C-17's tire pressure (Figure 5.9) is slightly higher than that for the C-5. Differences in tire pressure affect the reaction of asphalt runways, but concrete runways are usually insensitive to tire pressure.
- **Wheel pattern.** The C-17's wheel pattern spreads the load over a smaller area than does the C-5's wheel pattern (Figure 5.10). Of course the C-5 is a larger aircraft, so that also needs to be taken into consideration. The LCN concept provides a way to account for the spacing of wheels, because it examines the runway's reaction to the combined loads of all of the pertinent wheels.

Trades Made to Save Weight Explain How the C-17 Came to Impose the Most Stress on Runways. The C-17 causes higher stress levels than the C-5 because of a deliberate trade-off made during its development. The 1982 Request for Proposal for the C-17 called for an aircraft with an LCN of 40 when landing with 120,000 lbs of payload and sufficient fuel for flying 500 n mi after delivery of the payload. Following selection of the prime contractor, the specifications for the aircraft were developed and the development contract was signed. During development of the specifications, a decision was made to accept an LCN 48 design to allow a lighter-weight landing gear (one with fewer wheels) (Figure 5.11). The weight saved in the landing gear meant

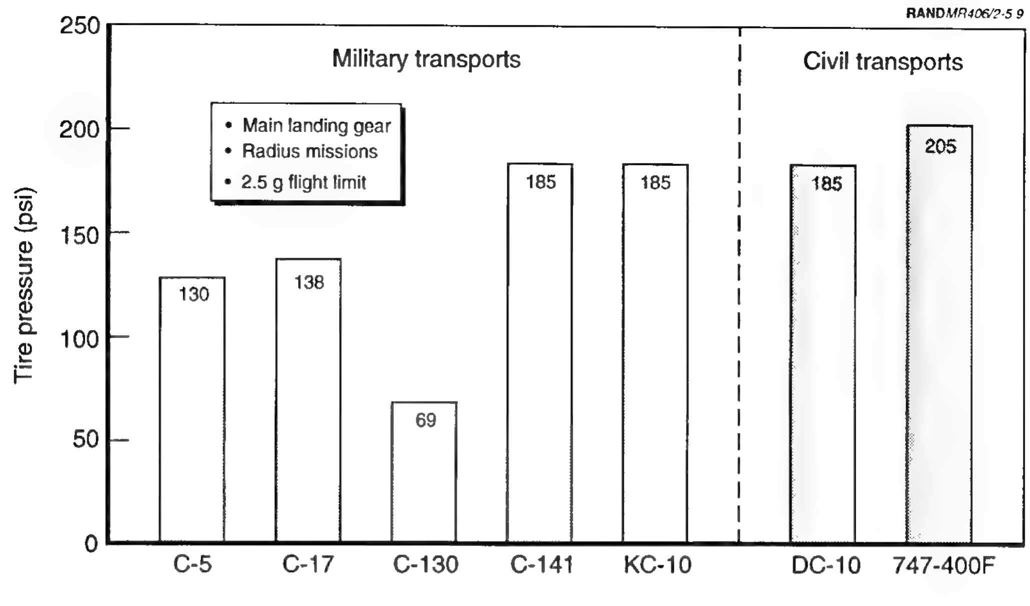


Figure 5.9—Tire Pressures

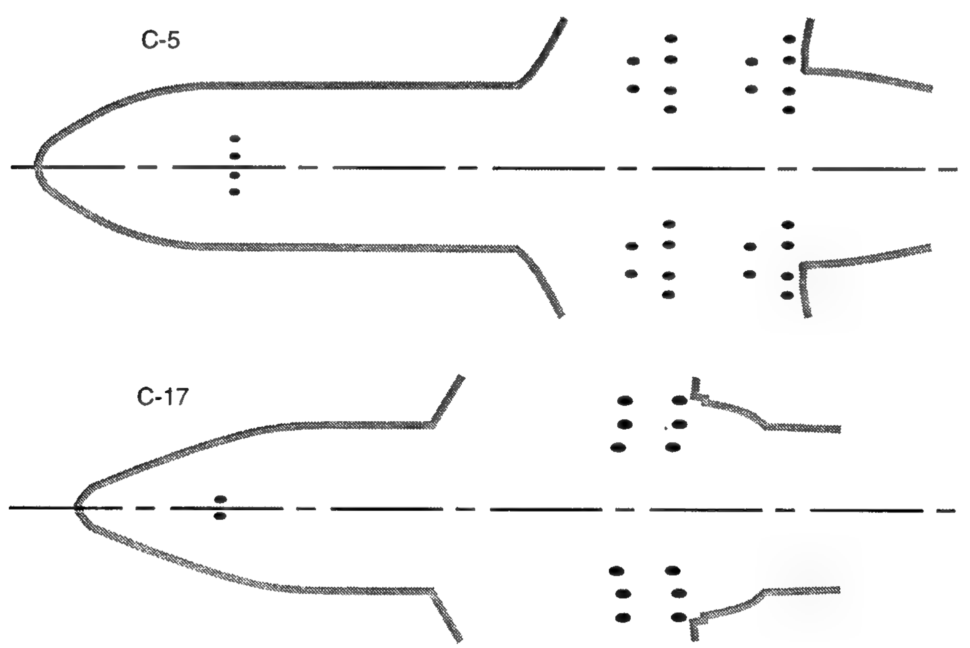


Figure 5.10—The C-5 Distributes the Load over a Wider Area

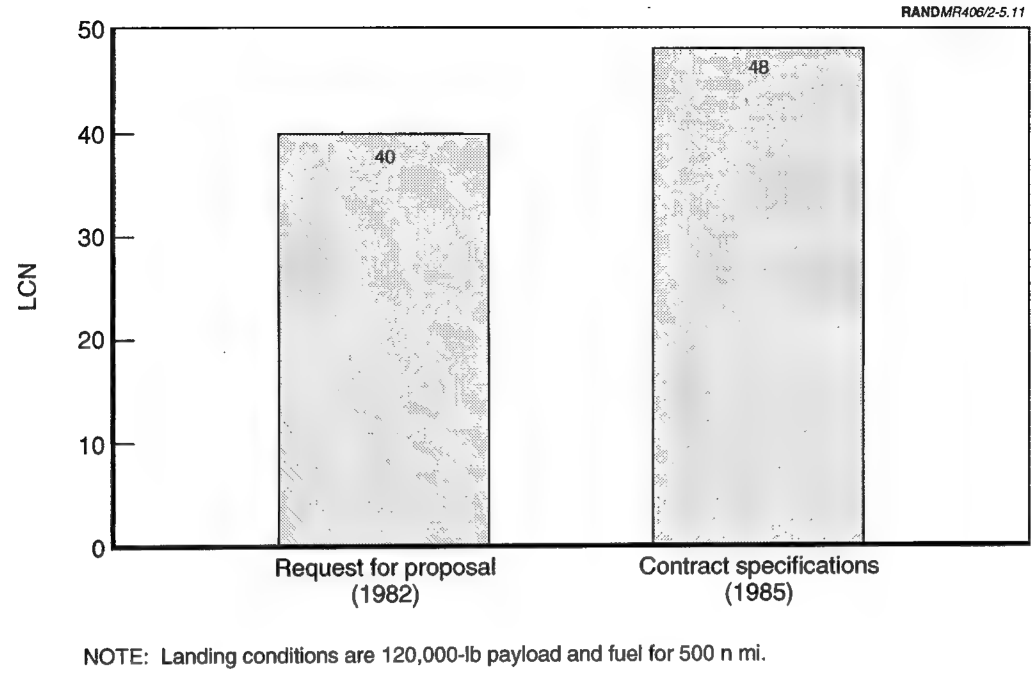


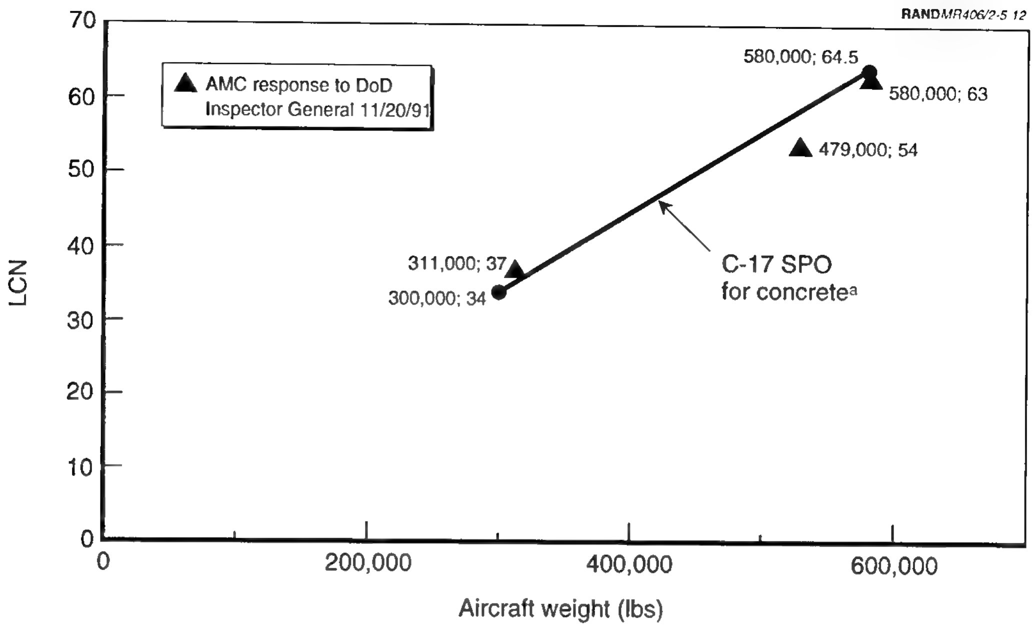
Figure 5.11—LCN for the C-17 Was Increased to Have a Lighter Landing Gear

that the aircraft would have a better opportunity to achieve other important performance objectives as well. The trade seemed reasonable in view of the many concrete runways in Germany that would be used by the C-17 in delivering tanks to reinforce NATO's frontline units.

As the LCN data provided by the C-17 System Program Office illustrate (Figure 5.12), aircraft weight significantly influences the LCN. The data in Figure 5.12 apply only to concrete runways and seem to be based upon assumptions of a medium to medium-strong subgrade. The C-17 SPO was unable to provide LCN values for asphalt runways, apparently because the development contract only requires calculations for concrete runways. Because there are many concrete runways in Germany, such an emphasis would be consistent with the focus on the reinforcement of NATO, which drove the design and development of the C-17.

U.S. Army Corps of Engineers Assessed Runway Stresses Caused by Transports

From the literature, we found one comparison of transport aircraft that fully described the assumptions about the pavement and subgrades that were used to assess the relative reactions of runways and the accompanying maximum stress levels. The calculations were performed by the U.S. Army Corps of Engineers for the C-5, C-17,



[a]Data for asphalt not available because contract does not require the calculation.

NOTE: Tire pressure is 138 psi.

Figure 5.12—C-17 Aircraft LCN Data Provided by the Air Force

C-130, C-141, and other aircraft.[14] For a given landing condition, their results (Figure 5.13) show the following for most concrete or asphalt runways and for most subgrade conditions:

- The C-5 and the C-130 cause comparable maximum stress levels in runways.
- The C-17 and C-141 cause comparable maximum stress levels.[15]
- The C-17 and C-141 cause significantly higher maximum stresses than the C-5 and C-130.

The Corps of Engineers performed their calculations using the ACN approach to assessing runway reactions and maximum stress levels.[16] The higher the ACN value,

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[14]*Aircraft Characteristics for Airfield-Heliport Design and Evaluation*, U.S. Army Corps of Engineers, Engineering Technical Letter 1110-3-394, September 1991.

[15]In Operation Restore Hope, operations into Baledogle, Somalia, were suspended after a dozen C-141 landings damaged the asphalt runway. The Defense Mapping Agency's LCN 72 rating for the runway had indicated that the C-141 should have been able to use this runway. An Air Force advance team also assessed the runway prior to the start of operations and judged that it should be suitable for use by C-141s. Because our research finds that the C-17 and the C-141 place comparable stresses and strains on runways, this incident has implications for the ability of the C-17 to use austere airfields, such as Baledogle.

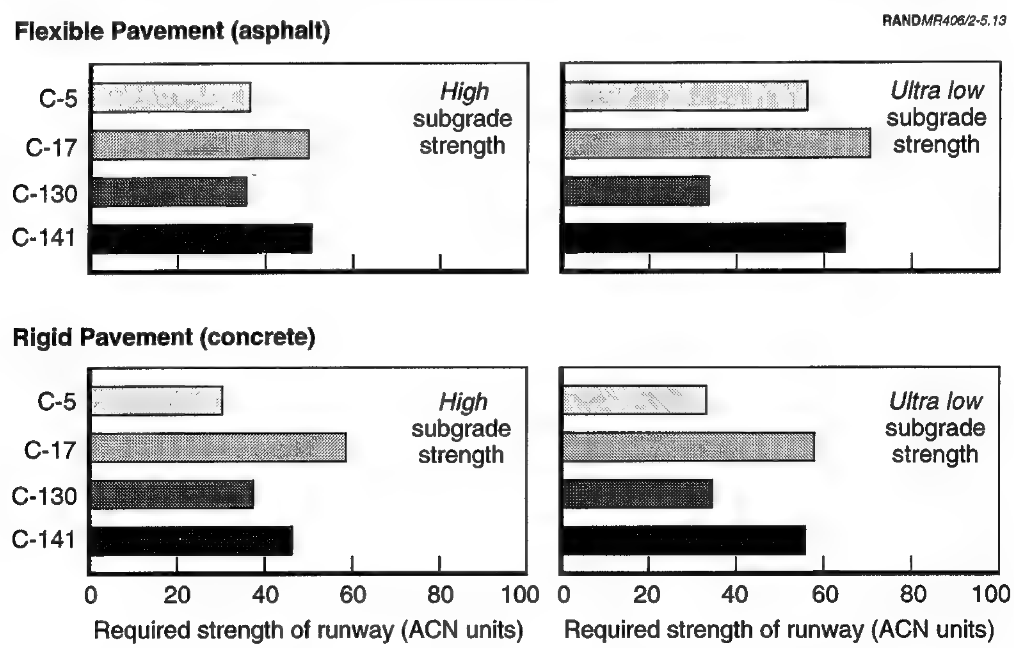
[16]See U.S. Army (1991) and Holliway (1990).

the greater the stress levels. The ACN concept includes the natural soil characteristics in the calculations for both flexible (asphalt) and rigid (concrete) runways.

Figure 5.13 illustrates one of the problems with AMC's application of the LCG approach. As applied, the approach ends up making no distinction between the C-5 and the C-17. The stresses caused by each are deemed to be close enough so as to be inconsequential. The approach also makes no distinction between flexible and rigid pavements. In effect, all of the differences between the C-5 and the C-17 in Figure 5.13 end up being treated as inconsequential. This is unfortunate, because the differences are real, and they are accurately portrayed by the information displayed in the figure.

RAND Confirmed Corps of Engineers Comparative Assessment of Stress Levels

Independent calculations by RAND—using the LCN system—verified the Corps of Engineers results. The LCN information was also needed for the airfield-access analysis, because the airfield databases use the LCN system. Calculations of LCNs by RAND ensured that consistent assumptions were used in evaluating each aircraft. Because concrete and asphalt runways react differently to aircraft loads, different



SOURCE: U.S. Army Corps of Engineers.

Figure 5.13—The ACN Measure Highlights the Differences Between the C-17 and C-5

procedures[17] were used to calculate LCN values for rigid (concrete)[18] and flexible (asphalt) runways.[19]

- **Rigid pavement runways.** A pavement-design computer program obtained from the Portland Cement Association provided the basis for our approach to calculating LCN values for the reaction of concrete runways to various aircraft loading conditions (Portland Cement Association, undated).
- **Flexible pavement runways.** The influence coefficient method was used to develop a spreadsheet approach to calculating LCN values for asphalt runways (Pereira, 1977).

For a representative direct-delivery condition in which aircraft weight is 80 percent of maximum gross weight, the LCNs in Figure 5.14 show that runway reactions and stresses vary widely not only by aircraft type, but also by type of runway construction. Because LCNs vary roughly in proportion to gross weight for most aircraft, the values in Figure 5.14 can be scaled to approximate the LCN for other aircraft weights, such as the second condition of interest (65 percent of maximum weight).

Comparison of the trends in LCNs from Figure 5.14 might suggest an anomaly. For a given aircraft on a concrete runway, the weaker pavements have greater reactions, as reflected in higher LCNs. For the same aircraft on an asphalt runway, the thicker pavement shows a greater reaction, as reflected in higher LCNs than the thinner pavement. Because asphalt pavements lack the beam-like property of concrete pavements, the influence of neighboring wheels is not felt near the surface. Thus, a very thin asphalt pavement will only experience the loads of the wheel immediately above, assuming the underlying soil is strong enough to bear the loads without experiencing large deformations. At some greater depth, the combined influence of multiple wheels will come to bear on the underlying soil. If the combined loads at that point are too great for the bearing capacity of the soil, the soil will permanently deform, and the soil and pavement above will similarly reflect the permanent deformations of the underlying soil. Thus, the reaction of an asphalt runway is a function of both the pavement reaction as reflected in the LCN measure as well as the strength of the underlying soil. Thus, the LCNs for asphalt runways in Figure 5.13 assume that the underlying soil is sufficiently strong to bear the aircraft loads.

Figure 5.14 further illustrates one of the problems with AMC's application of the LCG approach. Again, as applied, the approach ends up making no distinction between

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[17]See Brown and Thompson (1973) and Hay (1969) for landing-gear characteristics used in such calculations.

[18]We used the LCN concept to estimate the runway's reaction in terms of the maximum stress at the interface between the concrete pavement and the underlying subgrade material. The LCN takes into account the combined strength of the subgrade and the natural soil. For a rigid runway with a given LCN rating, the durability of that runway will depend upon the concrete's characteristics for crack initiation, crack propagation, and fracture toughness, as well as the loads imposed by using aircraft.

[19]We used the LCN concept to estimate the runway's reaction in terms of the maximum stress at the interface between the bottom of the subgrade and the top of the underlying natural soil without accounting for the strength of the underlying soil. For a flexible runway with a given LCN rating, the durability of that runway depends upon the strength of the underlying soil, as well as the loads imposed by using aircraft.

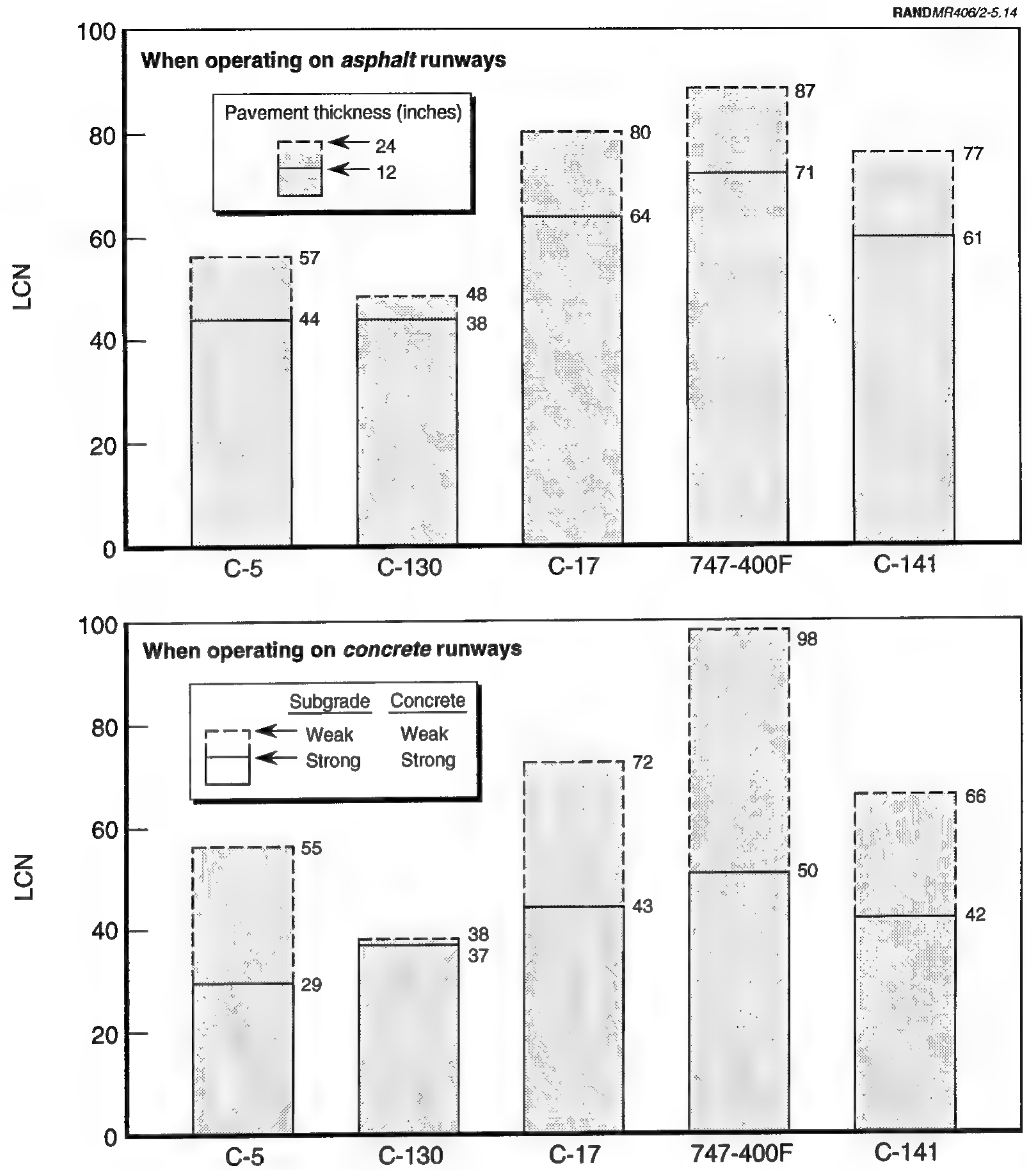

Figure 5.14—Aircraft LCN When the Aircraft Weight Is 80 Percent of Maximum

the C-5 and the C-17. All of the differences between the C-5 and the C-17 in Figure 5.13 end up being treated as inconsequential. Moreover, as AMC has applied the LCG approach, it has used LCNs calculated for rigid runways to evaluate the suitability of runways that were constructed from asphalt. This failure to distinguish among pavement types is important, because asphalt runways outnumber concrete runways by over six to one, and aircraft LCN values for flexible (asphalt) pavements can be higher than for rigid (concrete) pavements, as illustrated in Figure 5.14.

C-17 AND C-5 HAVE COMPARABLE ACCESS WHEN RUNWAYS ARE NOT OVERSTRESSED

The simplest case to evaluate is the one where runways are not stressed beyond the limits that airfield operators set to avoid accelerated wear. We do this first for U.S. airfields and then for foreign airfields. Later, we consider how allowing for operations that overstress runways and cause accelerated wear during an emergency can increase airfield access.

Analysis of U.S. Airfields Shows Comparable Access for a C-5 and a C-17

To analyze the comparative ability of different transports to use U.S. airfields without causing accelerated runway wear, we used two sources of information. One was a database from a 1982 RAND study,[20] the other was AMC's Airfield Suitability Report database.

Aircraft Causing High Stresses Have Limited Access to U.S. Airfields. The 1982 database was used to explore the importance of considering both a runway's length and stress (as reflected in LCN ratings) when examining the question of comparative access to airfields (Figure 5.15). Table 5.2 shows that most runways with LCNs greater than 40 are at least 6,000 feet long. Generally, short runways do not have high LCN ratings, although there are some exceptions. For example, out of the 2,351 airfields in Table 5.2, only 60 airfields have runways less than 6,000 feet long and LCN ratings higher than 40.

AMC's 1992 Database Confirms That High Stresses Limit Access to U.S. Airfields. We analyzed the implications of the differences in LCN on access to those U.S. airfields in the AMC's Airfield Suitability Report database. Of the 830 U.S. airfields in the database, the C-5 could operate at maximum gross weight at 203 airfields, whereas the C-141 could use 174. By limiting weights to 80 percent of the maximum gross weight, to lower runway stresses, the C-5 could use 256 airfields, whereas the C-141 could use 283 airfields (Figure 5.16). Thus, although the C-5 is a larger aircraft, and requires a wider runway, AMC's assessments show that its ability to use U. S. airfields is comparable to the ability of the C-141. Recall that the C-141 and the C-17 impose comparable stresses on runways.

Analysis of Foreign Airfields Confirms Comparable Access for a C-5 and a C-17

For foreign airfields, we again used two sources of information to analyze the comparative ability of different transports to use runways without causing accelerated

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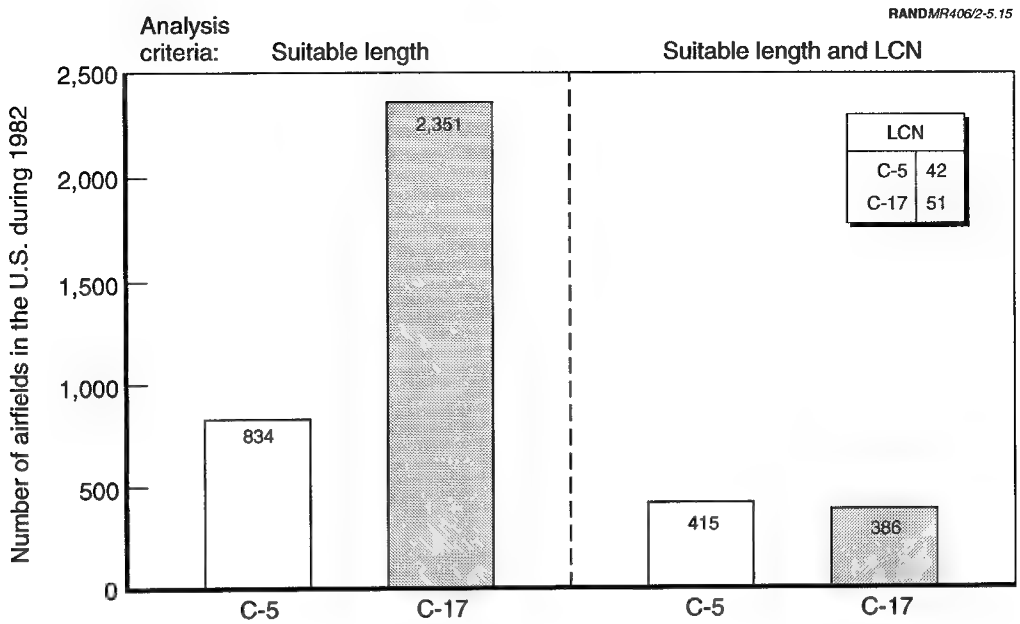
[20]We thank James Quinlivan for sharing the database that he developed for that research.



NOTES: Radius missions with 2.5 g flight limit; minimum runway length (ft): C-5 ≥ 6,000, C-17 ≥ 4,000.

Figure 5.15—LCN Influences Number of Suitable Airfields in the U.S.

Table 5.2

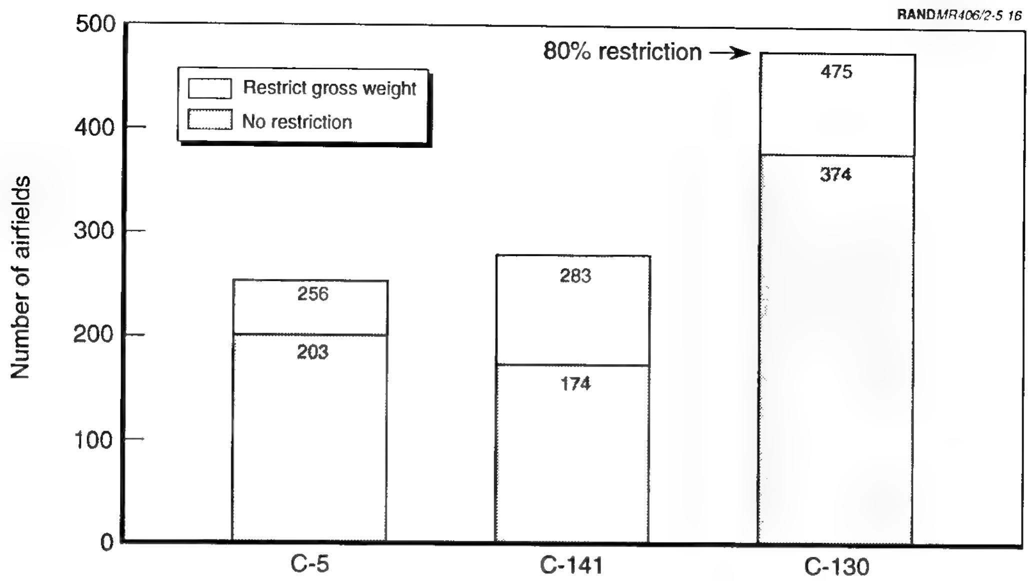
Most Short Runways Are Low in Weight-Bearing Capacity (number of airfields in the U.S.)

Runway Weight-Bearing Capacity	Short Runway 4,000–5,999 ft	Long Runway ≥ 6,000 ft
Low (LCN ≤ 40)	1,457	402
High (LCN > 40)	60	432

wear. One source was the AMC's Airfield Suitability Report database; the second is DMA's Automated Airfield Information File (AAIF).

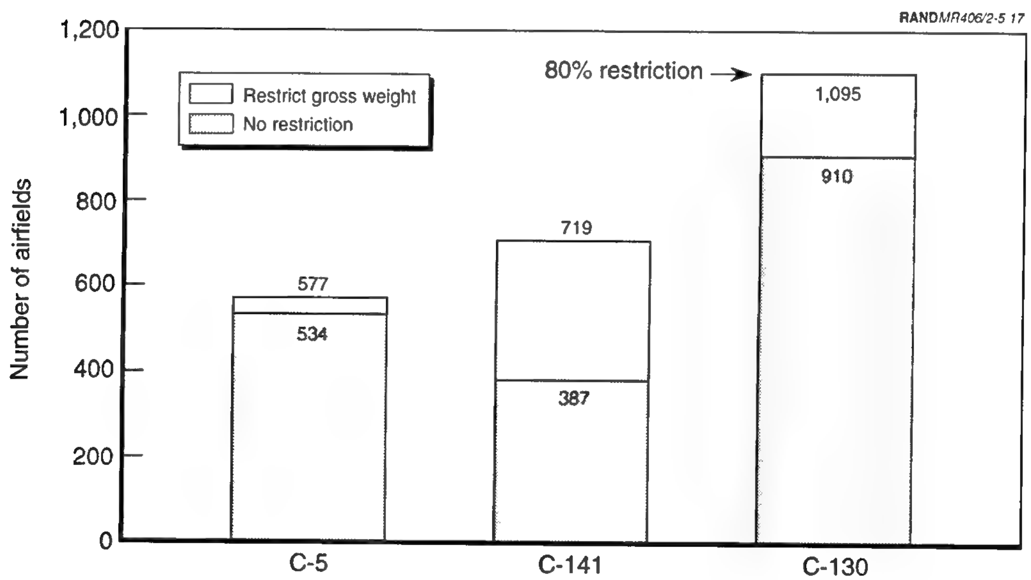
AMC's Database Illustrates Access Limitations for Foreign Airfields. To examine the implications of the differences in LCN on access to en route airfields, we used AMC's Airfield Suitability Report database. Of the 1,718 foreign airfields in the database, the C-5 can operate at maximum gross weight at 534 airfields, whereas the C-141 can operate at only 387 because of the higher stresses it creates (Figure 5.17). Again, we note that the C-17 and the C-141 impose similar stresses on runways for comparable mission conditions.

DMA Database Illustrates Access Limitations for Foreign Airfields. To further explore the airfield access question, we obtained a copy of the DMA airfield information database that contains about 10,000 airfields that have runways large enough for



SOURCE: MAC/XOVFP airfield suitability assessments for routine operations at 830 U.S. airfields.

Figure 5.16—Routine Access to Many U.S. Airfields Means Restrictions on Gross Weight



SOURCE: MAC/XOVFP airfield suitability assessments for routine operations at 1,718 foreign airfields.

NOTE: Excludes U.S. and former Soviet Union and its allies.

Figure 5.17—Nondestructive Use of Foreign Airfields May Require Restriction on Gross Weight

the C-17. The DMA database excludes the United States, China, and the former Soviet Union and its allies.

Figure 5.18 shows airfield access results for the C-5, C-17, and 747-400 for two conditions. The first condition assumes strong subgrades for all the runways in the DMA database. The second condition assumes weak subgrades for all runways. Between 1,500 and 2,100 airfields can be used by the C-5 or the C-17 without imposing accelerated wear. About one-third that number of airfields can be accessed by the 747-400 (500 to 800 airfields). These airfield counts are based on the assumption that the aircraft are operating at 65 percent of their maximum gross weight, a realistic condition for a destination airfield where the aircraft will be unloaded and refueled prior to departure. For the case of deliveries to APODs lacking refueling capabilities, airfield access would be reduced due to higher landing weights.

Because ramp space and taxiway constraints are also important considerations, we conducted a more detailed analysis for the airfields in Africa. For the C-5 and the C-17, Figure 5.19 shows that these aircraft have comparable access after accounting for runway and taxiway constraints. For example, about 40 airfields in Africa have ramps with at least 1.5 million sq ft that either the C-5 or the C-17 could use. There are about three times as many airfields with ramps of at least 0.5 million sq ft that either aircraft could use.

Our early research on the airfield-access issue had focused on the possibility of conducting airlift operations in an area remote from seaports, such as the mountains of Peru. Figure 5.19 shows there are some airfields that only the C-5 could access, and

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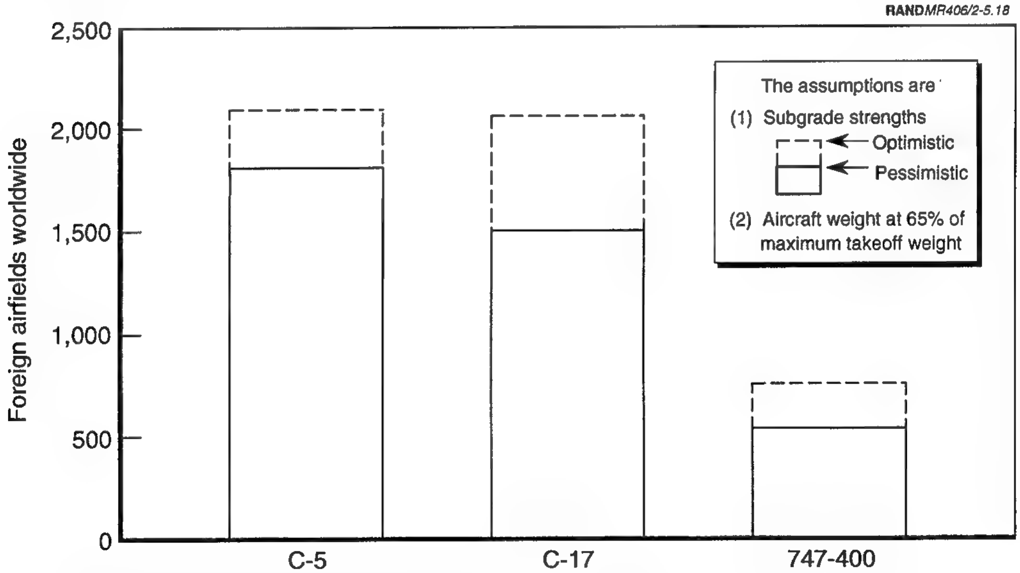

NOTE: Except China and the former Soviet Union and its allies.

Figure 5.18—Airfields with Runways That May Be Used Without Exceeding Economic Limits for Wear

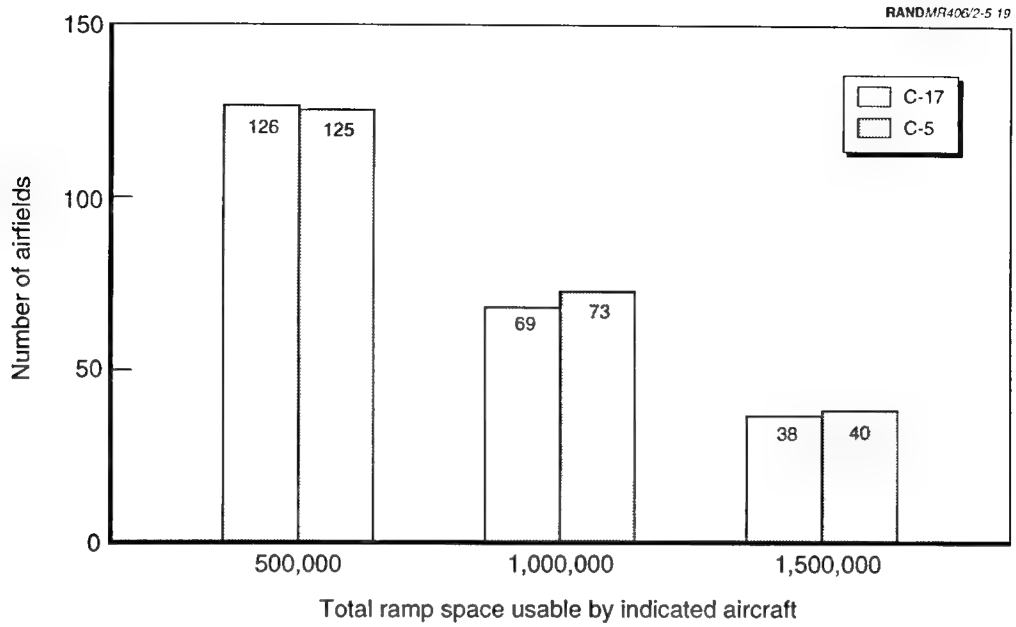

Figure 5.19—Airfields in Africa with Suitable Runways, Taxiways, and Ramps

there is an airfield that only the C-17 could access. Usually, however, both aircraft could access most of the airfields illustrated in Figure 5.20.

The bottom line is that the C-5 and the C-17 appear to have comparable abilities to access airfields, given an assumption of no accelerated wear due to operations that overstress the runway.

WHETHER C-17 HAS MORE ACCESS TO OVERSTRESSED RUNWAYS IS AN ISSUE

In an emergency, AMC intends to make maximum use of available runways, make repairs as necessary, and move airlift operations to other runways in the event that a runway becomes too difficult to repair. This opens the question of whether there are more airfields to consider. In its analyses[21] of using overstressed runways, AMC has judged that both the C-5 and the C-17 could operate on paved runways that DMA has assessed to have an LCN as low as 20.

An LCN 20 Concrete Runway Would Crack the First Time a C-17 Used It

To understand the potential implications of a C-17 using a new concrete runway with a DMA rating of LCN 20, we designed several such runways and then analytically assessed how they would perform in a test. Without exception, the maximum stress

[21] Military Airlift Command analyses in 1988 and 1991.

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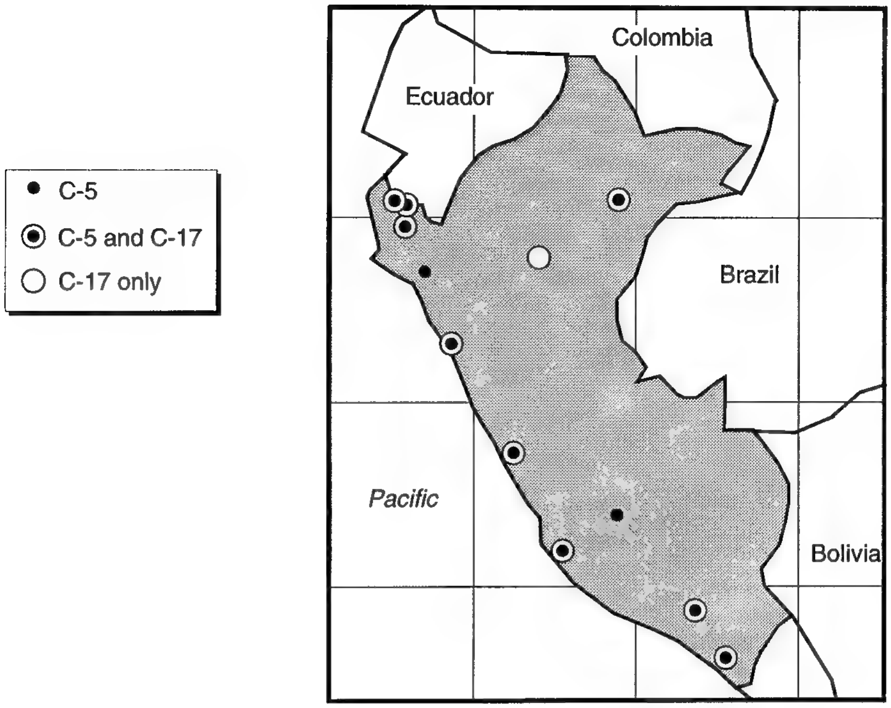


Figure 5.20—Airfields in Peru Capable of 500 Operations of the C-5 and/or the C-17

exceeded the rupture stress for concrete by at least 30 percent. Presumably, the concrete pavements would experience general area cracking the first time they were used. When used by a C-5, the maximum stresses exceeded the rupture stress by up to about 10 percent.

These results suggest that a single operation by a C-17 would create multiple breaks in the runway pavement. In subsequent operations, the pavement may act like a flexible pavement or perhaps even a gravel runway, depending upon the severity of the ruptures. There is a further issue of whether the failing runway would result in such an uneven distribution of loads within the main landing gear as to cause catastrophic failure of the gear structure with unknown consequences for the aircraft and its crew.

This analysis was conducted with the aid of an industry standard computer program that was used to design and analytically test eight different concrete runways.[22] Each runway was designed to be capable of supporting one month of operations (300 missions) by an aircraft with an aircraft LCN of 20 for the concrete strength and subgrade conditions specified for each runway design. The characteristics of the eight runways are summarized in Figure 5.21 in terms of the calculated thickness of con-

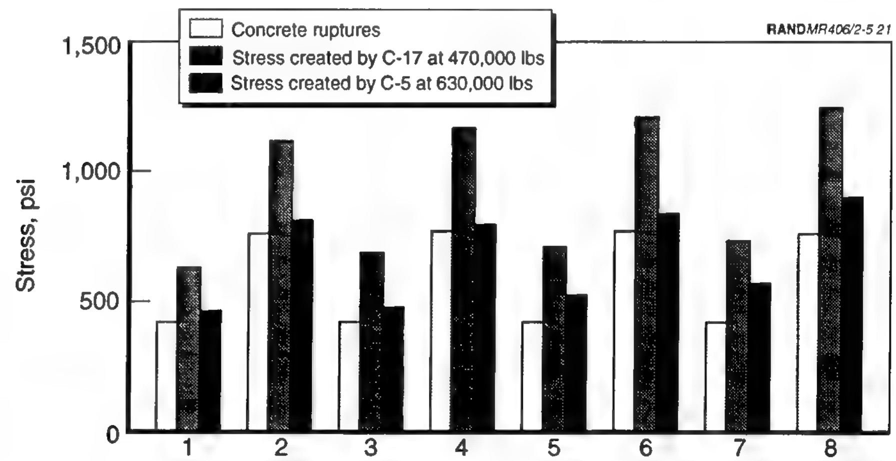
[22]See Portland Cement Association, undated, 1973, 1989, and 1992.

crete and the assumed conditions of concrete strength and subgrade. We varied the strength of the concrete and the reaction modulus (strength) of the subgrade to bracket the ranges of values encountered in runway construction. Figure 5.21 also presents the equivalent California Bearing Ratio for the subgrade.

LCN 20 Asphalt Runways Last Longer with a C-5 or C-130 Than with a C-17

The RAND Assessment Identified the C-17's Limited Ability to Use Low-LCN Asphalt Runways. We conducted a similar design and analytical test for asphalt runways.[23] In every instance, the runway lasted longer when used by either a C-5 or a C-130 than when used by a C-17.

The DMA database cites the C-131[24] as the reference airplane for many of the runways to which it has assigned an LCN rating of 20. We used the C-131 at its maxi-



		1	2	3	4	5	6	7	8
Concrete	Thickness (in.)	7.1	4.8	7.5	5.1	7.9	5.5	8.5	5.8
	Strength (psi)	2,000	4,000	2,000	4,000	2,000	4,000	2,000	4,000
Subgrade	Reaction modulus	500		300		150		80	
	CBR	50		26		5.5		2	
	Example	Cement treated				Crushed stone		Clay	

Eight runways that DMA procedures rate as capable of supporting one month of operations by aircraft with aircraft LCN of 20

Figure 5.21—One Landing by a C-17 or a C-5 Ruptures Concrete on Runways That DMA Procedures Rate at LCN 20

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[23]Design of flexible runways is addressed in U.S. Departments of the Navy, the Army, and the Air Force (1978).

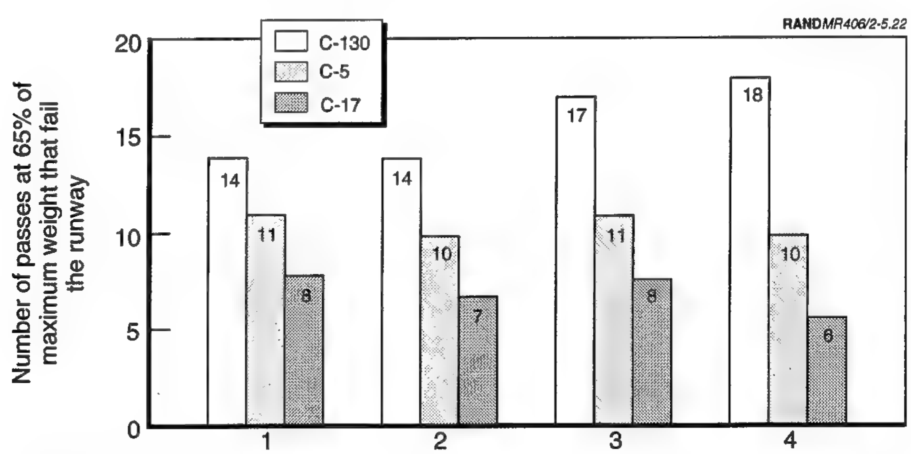
[24]The C-131 is a transport that is about one-third the weight of a C-130.

mum gross weight to design runways for four different subgrade conditions. The resulting pavement thicknesses are summarized in Figures 5.22 and 5.23 for the two interpretations for the DMA rating process. The runways in Figure 5.22 were designed to support about one month of operations (100 missions) by a C-131. The runways in Figure 5.23 were designed to support 10,000 operations by a C-131.

For each runway design, we then simulated repeated operations by a C-17, a C-5, and a C-130. In each case, we assumed that the aircraft were operating at a weight that was 65 percent of the aircraft's maximum gross weight. Depending upon the runway's design and the DMA rating process, we found the following:

- A C-130 was able to use the runway 2 to 6 times more often than the C-17.
- A C-5 was able to use the runway 1.3 to 4 times more often the C-17.
- For either interpretation of the DMA rating process, the number of C-17 missions that could be supported is from 6 to 55, assuming a new or freshly refurbished runway.

For the case of higher-gross-weight landings that would be associated with deliveries to APODs without refueling capabilities, even fewer operations would be possible. From this it seems clear that there are definite differences in the ability of the C-5 and the C-17 to use low-LCN runways. Moreover, the number of uses, even for a new runway, are not sufficient to support major airlift operations.



Asphalt	Thickness (in.)	6	12	18	24
Subgrade	CBR Example	10 Crushed stone	3	2 Clay	1
		Four runways designed for 100 passes by a C-131 at maximum weight (53,200 lbs)			

Figure 5.22—Runways Designed for 100 Passes by DMA's LCN 20 Reference Aircraft (the C-131)

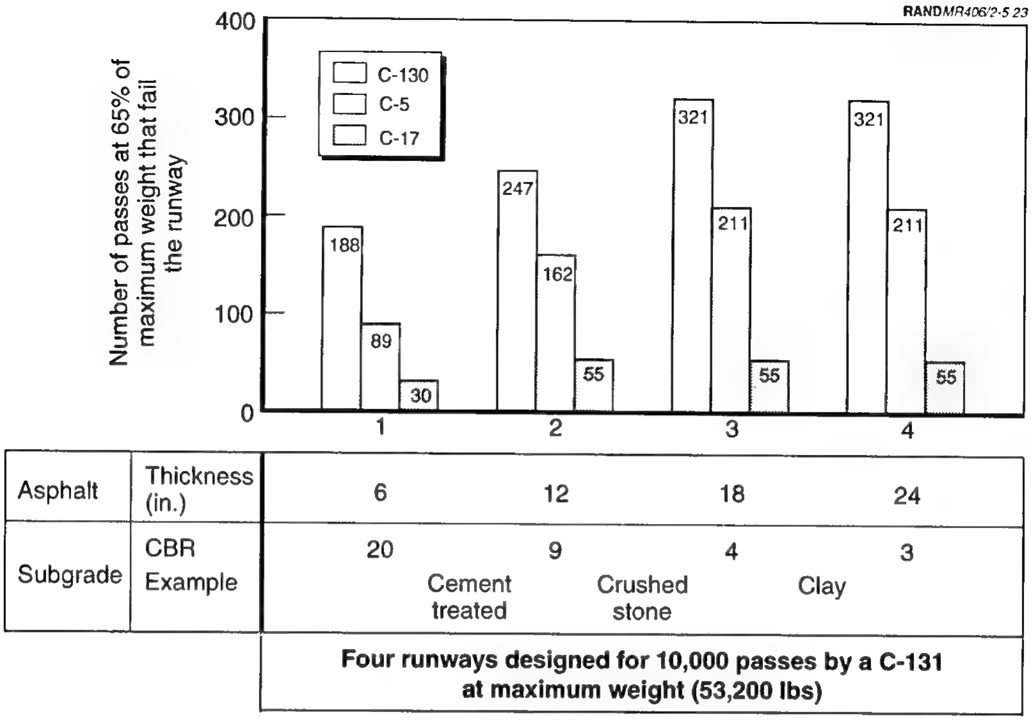


Figure 5.23—Runways Designed for 10,000 Passes by DMA's LCN 20 Reference Aircraft (the C-131)

Late 1982 Assessment by the Army Corps of Engineers for the AMC. At the request of AMC in late 1992, the Army Corps of Engineers also examined the question of operations on LCN 20 asphalt runways. Their results show that a C-17 at a landing weight for direct delivery to an austere airfield (80 percent of maximum weight) would be able to land fewer than 100 times. For 100 landings, the weight would have to be reduced to about 65 percent of maximum weight. At such a weight, either payload would be reduced or fuel would have to be provided to the C-17 at the austere airfield or there would have to be a combination of refueling and reduced payload.

RAND's estimates yielded 6 to 55 landings, depending upon assumptions about DMA's assessment process and the subgrade conditions (Figures 5.22 and 5.23). For the most optimistic set of assumptions, yielding 55 landings, RAND estimated that the C-5 could make four times more landings (runway width and length permitting) and the C-130 could make five to six times more landings than the C-17. In terms of throughput, the C-130 would deliver more tonnage before runway failure.

Even at 100 landings, however, if the C-17s in the Southwest Asia scenario all landed at an austere airfield with an LCN of 20, the airfield would last about four days based upon 26 arrivals daily. A smaller C-17 fleet with 60 PAA would yield 13 arrivals daily and a runway life of about eight days, according to the Army Corps of Engineers runway assessment for AMC.

Operating on Runways Down to LCN 20 Would Increase Airfield Access

As Figure 5.24 depicts, RAND's analysis found that there are 4,619 airfields with an LCN of at least 20 and a C-17–suitable runway length (at least 3,000 ft) and width (at least 90 ft). However, only 3,400 of these airfields have paved surfaces. (We treat the case of unpaved surfaces later.)

For concrete runways, an LCN of 20 is less than half of the RAND-calculated LCN value for the C-17. However, most of the world's paved runways are asphalt (Figure 5.24). For asphalt runways, an LCN of 20 is less than a third of the RAND-calculated LCN value. Although our independent technical evaluation has failed to find any test data that would confirm the prudence of operating on such a low-LCN asphalt runway, we have nonetheless explored what difference it would make, should it prove to be practical to operate on such runways.

Figures 5.25 through 5.28 summarize airfield counts from the DMA data file for two pavement conditions: asphalt and concrete. There are also two runway-width conditions: 90 ft and 147 ft. The C-17 can operate on runways with a minimum width of 90 ft, whereas the C-5 requires a minimum width of 147 ft. Figure 5.25 should be used when examining accessible airfields worldwide for the C-17 (excluding the United States, China, and the former Soviet Union and its allies). Figure 5.26 should be used for the C-5. Both Figures 5.25 and 5.26 pertain to asphalt pavements.

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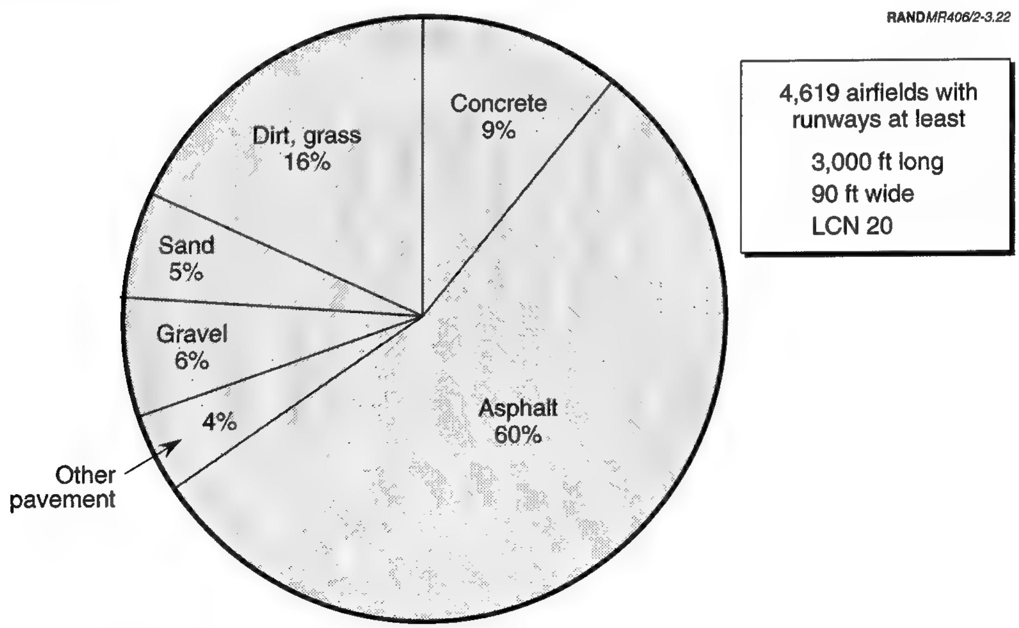
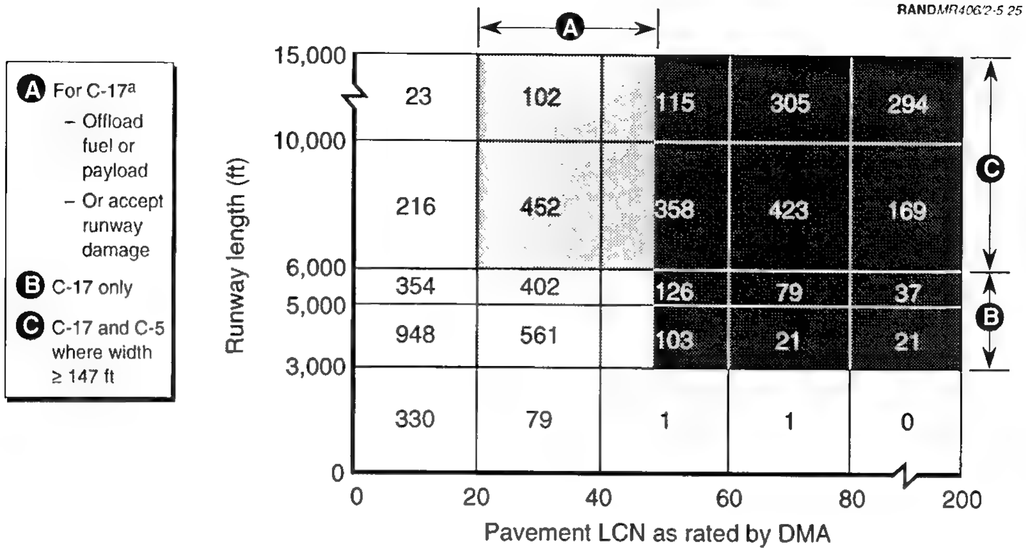


NOTE: South America, Africa, and the Middle East.

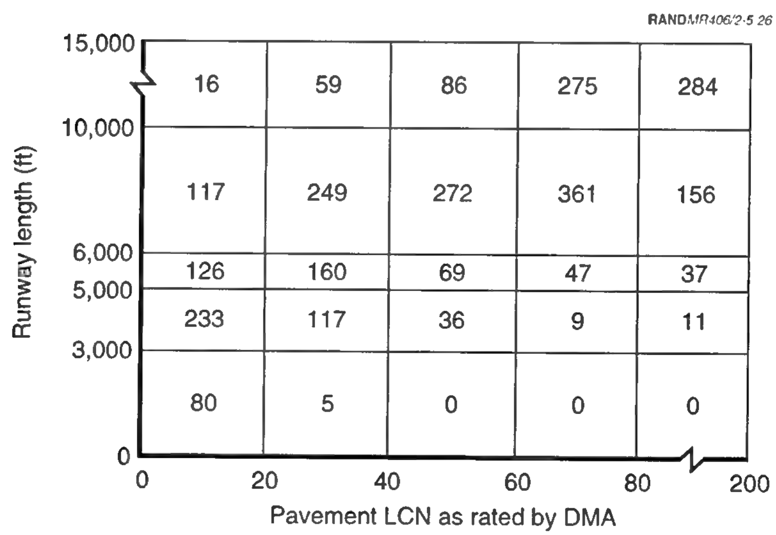
Figure 5.24—Airfields with a Runway Large Enough for the C-17 and with at Least an LCN 20 Rating from DMA



NOTE: Excludes the United States, China, the former Soviet Union and its allies.

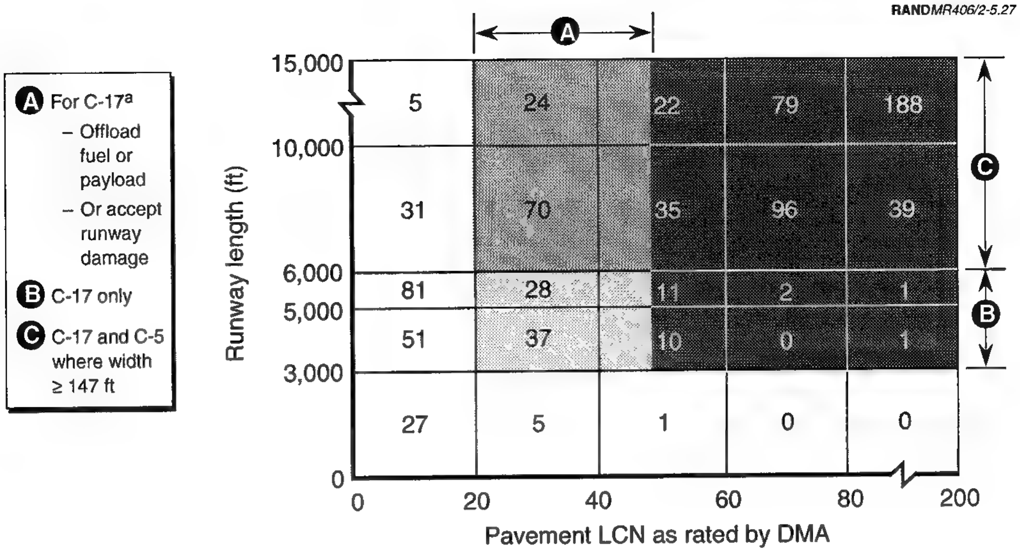
[a]Assumes C-17 satisfies LCN specification of LCN = 48 on asphalt runway with 120,000 lb payload and fuel for 500 n mi.

Figure 5.25—Number of Airfields Worldwide per LCN Category (minimum 90 ft wide, asphalt)



NOTE: Excludes the United States, China, the former Soviet Union and its allies.

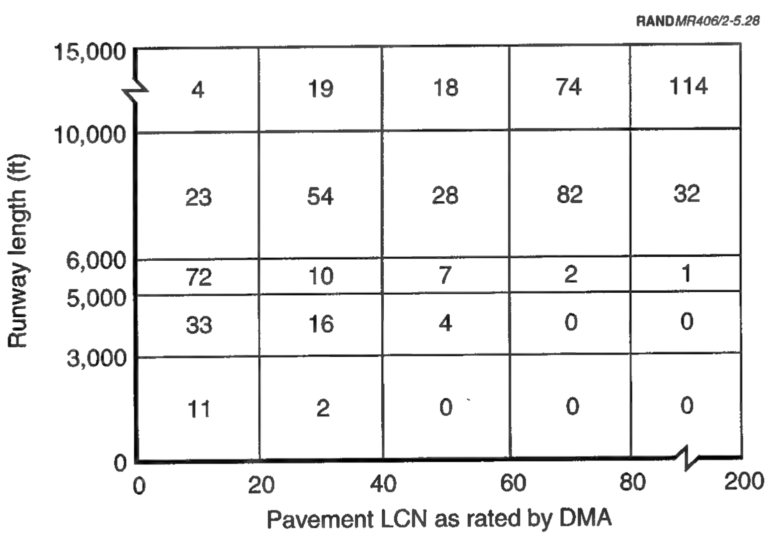
Figure 5.26—Number of Airfields Worldwide per LCN Category (minimum 147 ft wide, asphalt)



NOTE: Excludes the United States, China, the former Soviet Union and its allies.

[a]Assumes C-17 satisfies LCN specification of LCN = 48 on concrete runway with 120,000 lb payload and fuel for 500 n mi.

Figure 5.27—Number of Airfields Worldwide per LCN Category (minimum 90 ft wide, concrete)



NOTE: Excludes the United States, China, the former Soviet Union and its allies.

Figure 5.28—Number of Airfields Worldwide per LCN Category (minimum 147 ft wide, concrete)

If the C-17 Achieves the Specification LCN of 48 on Asphalt and Concrete Runways. Under this condition, the darkly shaded areas in Figures 5.25 and 5.27 are the zones where the C-17 can operate without overstressing runways and without having to offload fuel or payload in order to operate. Below an LCN of 48, the C-17 can operate either at the expense of offloading fuel or payload or by overstressing the runway and causing accelerated wear.[25]

The darkly shaded areas of Figures 5.25 and 5.27 are divided into two subareas, designated B and C. Because subarea B contains runways too short for the C-5, this is the domain where the short-field capability of the C-17 allows it to access airfields that cannot be used by the C-5.[26] If the aircraft LCN for the C-17 operating on asphalt meets the specification value, Figure 5.25 shows the C-17 uniquely accessing 37 + 21 + 79 + 21 + (12/20) × (126 + 103) = 295 airfields, based on its short-field capability. If, on the other hand, the aircraft LCN on asphalt turns out to be 60, then Figure 5.25 shows the C-17 uniquely accessing 37 + 21 + 79 + 21 = 158 airfields based on its short-field capability.[27]

If the C-17 Can Operate on Runways Down to LCN 20. The light-gray areas of Figures 5.25 and 5.27 highlight C-17 uniquely accessible airfields (based on its short-field capability) in the range of LCN 20 to 48:

For asphalt

$$(8/20) \times (125 + 103) + 402 + 561 = 1{,}054.$$

For concrete

$$(8/20)(11 + 10) + 28 + 37 = 73.$$

If the C-5 can operate on LCN pavements at least as low as the C-17, Figure 5.26 shows that it too would benefit from increased access to airfields. The C-17 would seem to benefit more than the C-5 from overstressing runways and allowing accelerated wear. However, that assumes that an LCN 20 cutoff is appropriate for both aircraft. It can, of course, be argued that, since the stresses caused by the C-5 are lower than those caused by the C-17, using a common cutoff is unreasonable.

Rapid Runway Repair Is the Air Force's Fallback Position. It is the Air Force's fallback position that rapid-runway-repair capabilities have been perfected enough to cover needs that might arise for repairing low-LCN runways. However, much of the emphasis in developing such capabilities has been placed on the problem of repairing local-area damage caused by the detonation of munitions. Broad-area damage due to accelerated wear may place a different level of demand on such capabilities. Rapid-repair capabilities for concrete pavements, for example, may have limited

[25] It is unclear, however, whether the specification includes asphalt runways. The asphalt LCNs in Figure 5.14 are much larger than 48 for all subgrade conditions.

[26] The C-5 could use runways as short as 5,000 feet for many conditions of altitude and weather. In using 6,000 feet for this discussion, we give the benefit of the doubt to the C-17.

[27] Figure 5.14 shows an LCN of 64 for a 12-inch pavement.

utility for repairing broad-area damage to the subgrade underlying an asphalt pavement.

Moreover, other major uncertainties affect the idea of relying on accelerated wear: the existing conditions of the runways; the rate at which remaining runway life gets consumed; and the point at which, because of subgrade failure, the maintenance chore becomes a substantial disruption to ongoing airlift operations. Although we have not measured in absolute terms the airfield-access capabilities of the transports of interest to this research for the conditions of overstressed runways, certain comparative findings have emerged:

- The C-17 and C-141 will consume remaining runway life more rapidly than the C-5 and C-130 for comparable conditions of landing gross weight as a percentage of maximum gross weight, subgrade conditions, and pavement conditions.
- The civil transports like the 747-400 are least flexible in terms of the number of airfields around the world at which they can operate, the number being somewhere in the neighborhood of 500 to 800, excluding the United States, China, and the former Soviet Union and its allies. In comparison, the C-141 and C-5 can operate at about three times that number of airfields.
- For large-scale airlift operations requiring many uses of runways, the C-17 may or may not have an operationally meaningful advantage over the C-5 when overstressing of runways is allowed.
- The C-130—under comparable assumptions about overstressing and accelerated wear—can conduct more operations on paved surfaces because of its ability to operate on narrower landing strips than does the C-17.

THE C-130 REMAINS A UNIQUELY IMPORTANT RESOURCE

The C-130 Has Greater Access to Paved Runways Than a C-17

Under comparable assumptions about the amount of runway stresses that are to be allowed, the C-130 can operate at many more locations due to its ability to operate on narrower and weaker runways than the C-17. The C-130, for example, uses roads for landing strips.

The C-130 Has Greater Access to Unpaved Runways Than a C-17

The C-130 has a further demonstrated advantage over the C-5 and the C-141 in operating on unpaved surfaces. It is expected that the C-130 will also maintain a significant advantage over the C-17 in terms of operating on unpaved surfaces, not only because of the lower strength requirement for the landing surface for the C-130 as contrasted to the C-17 but also because of the differences in the propensity for propulsion systems to suffer foreign-object damage when operating on unpaved surfaces.

As the unpaved runway tests for the C-5 demonstrated, turbofan engines ingest very-high-velocity air streams that pick up loose material lying on unpaved runways. Because of the engine failures during the C-5 test, the C-5 has been barred from operating on unpaved surfaces. Generally, turboprop aircraft, such as the C-130, are less prone to foreign-object damage of their engines, because the air stream entering the engine has a much lower velocity. Because the C-17 has a turbofan engine, its engines also are vulnerable to ingesting loose material that may damage its engines, as the C-5 experienced in its unpaved runway test. Because of the risk of ingesting foreign objects into the engine, the C-17 may not be used on unpaved runways.[28] This aspect needs further examination, however, because other factors such as engine placement also influence the propensity for foreign object damage. Because the C-17's engines are placed closer to its wing than the C-5's, it may be less vulnerable to such damage than the C-5.

However, because the specifications for the C-17 included operations on gravel runways, we examined the comparative capabilities of the C-17 and the C-130 to operate on such runways (Figures 5.29 and 5.30).[29] Regardless of assumptions about the underlying soil, gravel thickness, and condition of the runway, the C-130 delivered more payload than the C-17 before the runway became unusable.[30]

In summary, we can say with certainty that the C-130 has greater access to airfields than the C-17, based upon the results in Figure 5.17 for the paved runways in AMC's database, the analysis of accelerated wear for asphalt pavements, and the analysis of unpaved runways.

Upgrading the C-130 Design Would Increase Its Access to Airfields

Because the U.S. Southern Command has been procuring the C-27 transport to increase its access to airfields in Central and South America, we explored the possibility of updating the C-130 design to improve its runway performance with a new engine and to improve its weight distribution characteristics by redesigning its main landing gear. Figure 5.31 shows the potential of doubling the C-130's access to airfields. Whether such improvements could actually be achieved would need to be demonstrated by an appropriate test program.

In closing, from the vantage point of airfield access, the C-17 has yet to demonstrate a militarily significant and unique role that it might play in the airlift fleet.[31] The

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[28]Operation on an unpaved surface is part of the C-17 test program. Whether the C-17 proves suitable for routine operations on gravel and dirt airfields remains to be explored.

[29]To protect the engines from ingesting gravel and other loose material, there were considerations at one point in the development of the C-17 for attaching gravel shields to the engine inlets. The weight—and potential drag—of such shields would detract, however, from the aircraft's payload and range performance.

[30]See Gray and Williams (1968) and Headquarters, Department of the Army (1990) for evaluation methods for unsurfaced and gravel runways.

[31]Appropriate tests of the C-17's ability to operate on austere fields need to be completed and evaluated to fully assess its capabilities.

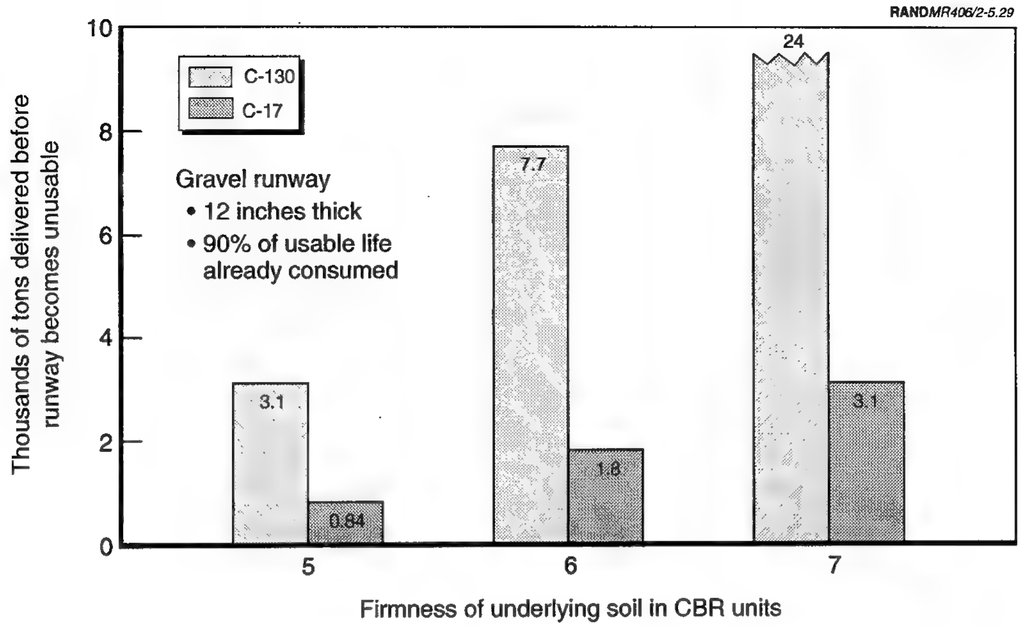

Figure 5.29—The C-130 Has Greater Throughput When Runway Life Is a Constraint and the Runway Is in Poor Condition

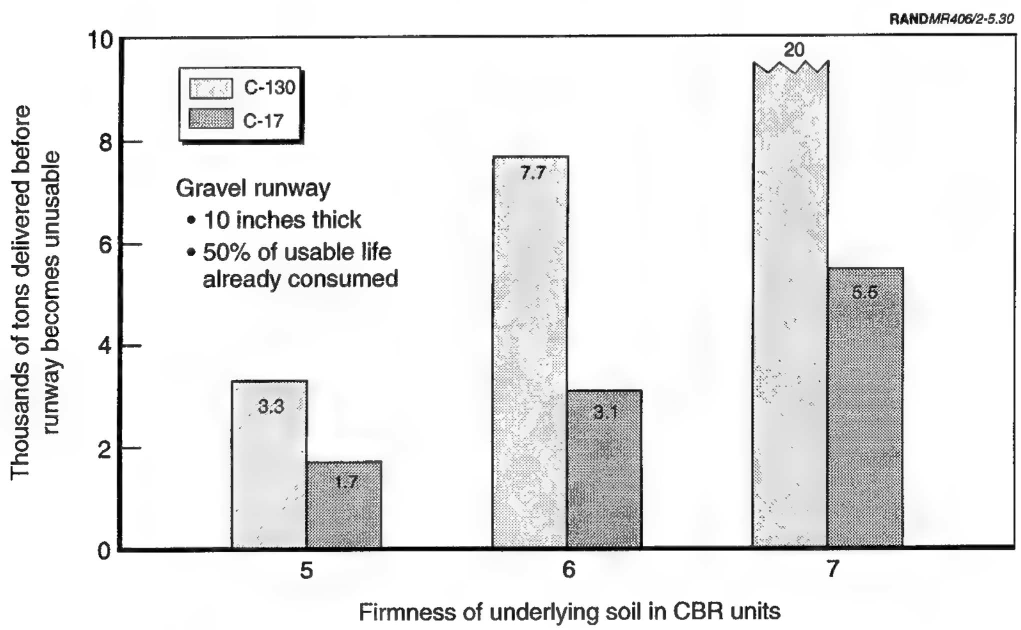

Figure 5.30—The C-130 Has Greater Throughput When Runway Life Is a Constraint and the Runway Is in Average Condition

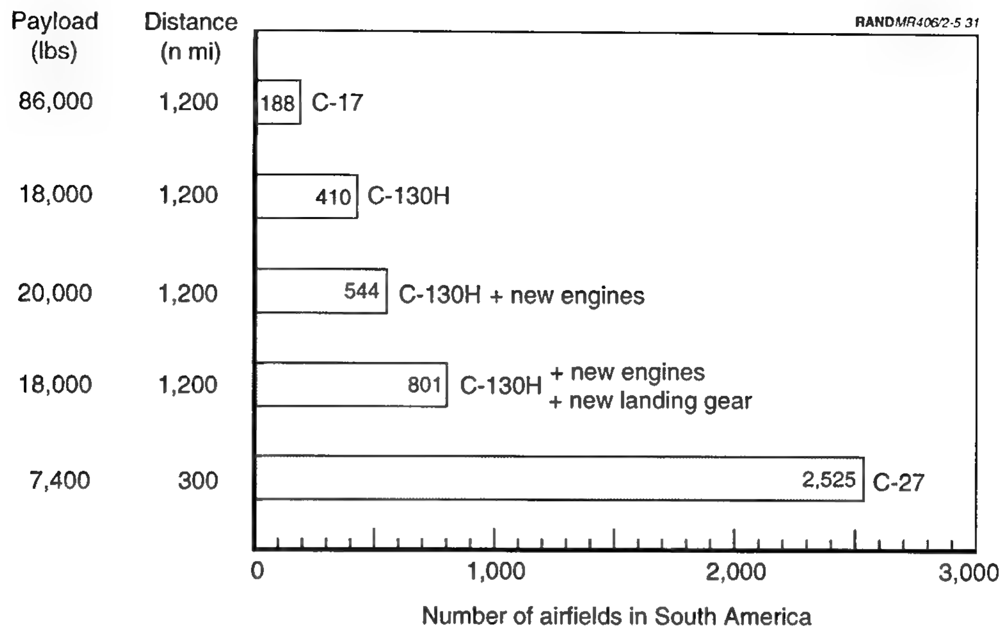

Figure 5.31—Airfield Access in South America Illustrates Value of Upgrading the C-130 Fleet

C-130 has. These issues need serious consideration as the DoD addresses the matter of the right mix for future needs.

C-17'S ACCESS TO AIRFIELDS IS MORE LIMITED THAN PREVIOUSLY ENVISIONED

The C-17's access to airfields is more limited than was envisioned when the aircraft's conceptual design was defined, because the aircraft's size and the designs for its engines and landing gear have changed. Consequently, it does not match the airfield-access capabilities of the C-130. Moreover, even though the C-130 cannot match the C-17's capability to deliver outsize materiel, the demands for airlift have shifted and no longer place the level of emphasis on outsize materiel that existed when the C-17 concept was defined. Moreover, the C-5 can use most airfields that the C-17 can use under normal restrictions on runway stress levels. Although the C-17 has the advantage of being able to use smaller runways, the C-5's offsetting advantage is in causing less stress on runways by distributing its weight over a much broader area.

Under emergency conditions where runways would be overstressed and used until failure forced interruption of use for runway repairs, the C-17 may have an airfield-access advantage of up to a factor of two over the C-5 but not over the C-130.

Chapter Six

CONCLUSIONS

Finding the right mix of military and civil airlift is an extremely complex and demanding task, because it involves difficult trade-offs among operational and cost considerations at a time when there is uncertainty about both the future uses of airlift and the funds that will be available to acquire, operate, and support airlift capabilities. Moreover, there are significant differences in the costs and capabilities of different fleet mixes, and the DoD must justify what it selects as the right mix at a time when there is extraordinary competition for resources.

Our research, conducted against the backdrop of conditions in 1992, responded to Air Force interest in exploring the cost-savings potential—and the wartime implications—of increasing the DoD's reliance on civil airlift. Although the military-style transports—and the military's operation of those transports—provide essential operational capabilities, fiscal constraints and the needs for additional airlift capacity have always forced the DoD to turn to other, lower-cost means of airlift for delivering some of the passengers and cargo. The greater efficiency of the civil-style transports in delivering some types of loads and the cost-effectiveness of the CRAF arrangements have provided that lower-cost means to augment military airlift capabilities.

To provide the Air Force with our best independent estimate of the right mix, our research has sought to balance the competing needs for resources that are created by two important attributes of the airlift fleet:

- Capacity to respond to major needs
- Flexibility to adapt to a wide variety of airlift circumstances.

Investing too heavily in capacity at the expense of flexibility can produce a large fleet with inadequate flexibility for important jobs. On the other hand, investing too heavily in flexibility can produce a very versatile fleet that is too small and without sufficient capacity for very large airlifts.

To find the right balance of capacity and flexibility, we made independent assessments for the key factors that influence the costs and capabilities of alternative fleets: (1) the airlift jobs for which the Air Force needs to be prepared, (2) the extent to which the Air Force can prudently depend upon the CRAF being made available to augment military airlift, (3) the abilities of alternative transports to use the world's airfields for major APOD operations, and (4) the average values that would be real-

ized for aircraft payloads, utilization rates, and block speeds when the airlift fleet (including CRAF) is used to conduct airlift operations for a specific scenario.

To maintain necessary capacity, we see a need for some shift in the mix toward the civil-style transport. To maintain necessary flexibility, we see a need to limit the amount of that shift and, at least initially, a need for the Air Force to be the operator of any civil-style transports that might replace retiring C-141s. At some future point, as CRAF arrangements continue to evolve and as the civil air-freight market continues to grow, it may be appropriate for such transports to be added to the CRAF to further reduce costs.

In 1992, we found that replacing up to two-thirds of the C-141 fleet with civil-style transports had significant merit on cost and capacity grounds, although it would reduce flexibility. Following an extensive documentation and review process, we believe that is still the case in late 1994.

In 1993, however, the warfighting CINCs decided that any such a reduction in flexibility would give up too much capability. Moreover, research conducted during 1993 had shown that our estimates for the size of the shift and the amount of the cost savings are sensitive to a few key parameters, for which wide differences in assessed values were emerging from different analyses. Estimates for these parameters (payloads, utilization rates, block speeds, load mix, and CRAF's availability) depend upon airlift scenarios, analytical methods, and assumptions used to evaluate airlift fleet performance. Thorough examination of the basis for such estimates is fundamental to understanding the reasons for differences in results. It is also fundamental to improving the analytical foundation for future decisions about the airlift fleet. To facilitate such examination, this volume and Volume 3 describe the analytical basis for our estimates. Appendix G of Volume 3 also suggests some initiatives that would help the DoD reduce the disparity of approaches to this kind of analysis.

Another important dimension of the right mix is using the mix to its full potential. Here the DoD seems to have important opportunities to leverage its investment in airlift capabilities by improvements in C^4 processes. Such improvements could facilitate improvements in other areas, including (1) making the best use of potential APOEs and APODs, (2) making the best use of aerial refueling, and (3) executing airlift operations to apply the capabilities of different types of transports more fully. These initiatives should also be considered as the DoD tries to balance the need for both airlift capacity and flexibility at a time when both the future uses of airlift and its future funding are uncertain.

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